X. *Researches on the Foraminifera.*

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PART I.

CONTAINING GENERAL INTRODUCTION, AND MONOGRAPH OF THE GENUS ORBITOLITES.

General Introduction.

THE tribe of Animals in regard to certain members of which I propose to offer to the Royal Society the results of my detailed investigations, is almost unknown, save by name, to many well-informed Naturalists; and has only of late received even a small measure of that attention, which its zoological and its geological importance, and its physiological interest, may fairly claim for it. Of the bodies which are now, on account of their general conformity to a certain plan of organization, grouped together under the designation *Foraminifera*, the greater proportion, being spiral multilocular shells, were long associated with *Nautili* and *Ammonites*, and were thus ranked as *Cephalopodous Mollusks* in the classifications of LAMARCK and CUVIER; whilst a few others, bearing more resemblance to certain kinds of corals, seemed naturally to take their places among *Zoophytes*.

Down to a comparatively recent period, scarcely anything has been known beyond the external characters presented by these testaceous or coral-like bodies; their internal organization has been very imperfectly examined; of their intimate structure, no attempt at elucidation has been made; and as to the nature of the animals of which they are the skeletons, the grossest misapprehensions and errors have prevailed. And though many important steps have been recently made in this direction, it is obvious that the methods which have been proposed for the classification of the large number of forms (apparently distinct from each other) that have been collected, described,

and systematized, must be provisional merely. No general foundation has yet been laid for that due appreciation of the *value of characters*, which, in the case of every natural group, must be based on the careful study of its own plan of organization, and of the modifications which this may undergo, and which cannot be safely deduced by analogy, from the study of any other group, however closely related. Far less can any such analogy be truly available, that is drawn from the higher forms of *Mollusca*, and applied to one of those simple types of animal structure, which are now commonly included under the general designation *Protozoa*.

Having been myself convinced, by the careful examination and extensive comparison which I have had the opportunity of making, as to the external characters and internal structure of certain Foraminifera, that neither in regard to the limitation of *species*, nor the association of these into *genera*, nor the grouping of genera into *Families* and *Orders*, is such an analogy to be in the least degree relied upon, I am prepared to show that the whole fabric which has been erected on the basis of it, is utterly insecure; and that every attempt to erect a new classification of the group, without a far more intimate knowledge of the anatomical structure and of the physiological history of the animals composing it, than has yet been sought for, must necessarily be premature and therefore unsound.

If, therefore, notwithstanding the large amount of labour which has been given to the study of this group, we are really as yet only at the very commencement of an exact acquaintance with it, I venture to think that any contribution towards a more intimate knowledge will be welcomed, by all such as consider that systematic arangements can only be of value, when based on an extensive comparison, not merely of the external forms, but of the internal organization, of the objects to be classified, and when carried out under the guidance of a competent knowledge of their Physiology as living beings. It may be well for me here to state, that the greater part of the results which I purpose to communicate in successive Memoirs, are based upon the examination, not of a limited number of individuals, but of three very extensive suites of specimens, which have been liberally placed at my disposal; the first of these series having been formed from the dredgings of Mr. J. Beete Jukes on the coast of Australia, into the possession of which I came through the instrumentality of my late friend Professor E. Forbes; the second having been furnished by the collection of Foraminifera made by Mr. Hugh Cuming on the shores of the Philippine Islands, and unreservedly given up to me by that gentleman for the purposes of scientific investigation; and the third being the admirably-arranged series in the possession of my friend Mr. W. K. Parker, who has for several years been patiently and industriously bringing together from various sources a set of illustrations of this group, which in many departments may be safely pronounced to be quite unique. The importance of the first two of these collections consists, not in the number of *species* they include, for this is comparatively limited; but, on the one hand, in the extraordinary development as to *size* which most of these species present; and on the other,

in the immense aggregation of *individuals* they contain, thus presenting the materials for a most full and complete investigation into that hitherto comparatively neglected subject, *the range of variation within the limits of species.* And the great value of Mr. Parker's collection lies in his having followed out this inquiry (first suggested to him by myself as the result of my examination of the other two collections) in regard to a much larger number of species, and with materials brought together from a much wider geographical area.

The question has been anxiously considered by me, in what mode I might render these materials most beneficial to the progress of science; and I have come to the conclusion, with the full concurrence of some of the most eminent Naturalists both of this country and of the continent, that I should be doing the most acceptable service, by instituting *a searching investigation into the entire history of such typical forms* of this remarkable group, as should be most fitted to afford satisfactory data for reasoning with regard to the rest;—including in this history, a minute examination of the structure, not only of the testaceous skeletons, but also (where this might be possible) of the soft animal body; a careful survey of the differences of form and aspect presented at different ages, so as to enable the history of any individual to be traced from its origin to its decline; a comparison of the variations both in external form and internal structure, presented by different specimens, sufficiently extensive to admit of the determination how far these variations are of value as *specific* characters, or how far they must be accounted merely individual departures from the ordinary type; a like comparison between the series collected in different geographical areas, so as to afford a safe basis for the determination of the range of the species, and the amount of its variation in *space*; and a further extension of this comparison to similar series obtained from the various geological strata in which the like forms may present themselves, so as to ascertain the range of the species and the extent of its variation in *time.* And if I should seem, in following out this plan, to have erred on the side of *over-minuteness*, I trust to receive credit for the real motive which has induced me to bestow so much elaboration on the work I have undertaken,—namely, the desire to furnish a thoroughly secure foundation, on the basis of which the labours of others, in whatever department of the inquiry, may be safely utilized in building up a complete and harmonious superstructure.

It had been my intention to preface the account of my own Researches, with a summary of the History of our knowledge of the group generally. This subject, however, has been so fully and satisfactorily worked out, in two of the most recent treatises on the subject,—that of MM. d'Archiac and Haime on Nummulites*, and that of Professor Schultze on certain forms of existing Foraminifera†, the latter

* See their "Monographie des Nummulites," forming part of their "Description des Animaux Fossiles du Groupe Nummulitique de l'Inde," Paris, 1853.

† Über den Organismus der Polythalamien (Foraminiferen) nebst Bermerkungen über die Rhizopoden im allgemeinen. Leipzig, 1854.

containing a most complete Bibliography,—that I do not feel it necessary to offer more than a mere sketch, marking out the principal periods into which this History may be divided.

The *first* period includes all the observations made and published in regard to these minute polythalamous bodies, from the time when they first attracted attention, down to the date (1825) when M. D'ORBIGNY grouped them together, as constituting a distinct type of structure. The observers whose labours during this period did most to prepare the way for their successors, were SOLDANI*, FICHTEL and MOLL†, MONTAGUE‡, and DENYS DE MONTFORT§.

The *second* period commences with the presentation to the Académie des Sciences, in 1825, of M. D'ORBIGNY'S "Tableau Méthodique de la Classe des Cephalopodes;" in which he first separated these chambered shells, under the title of *Foraminifera*, from the *Siphonifera*; still retaining the former, however, like the latter, as an order of Cephalopods. A large number of new forms were added by M. D'ORBIGNY to the list of those previously known; and he laid the basis of the classification which he has since more fully elaborated. No suspicion appears then to have crossed his mind, that the place of these bodies might be amongst the lowest, instead of among the highest, of the Invertebrata; and if his determination of their Molluscous nature was based on any actual observations of these animals in their living state, it is certain that such observations must have been of the most superficial character.

The *third* period, with which our knowledge of the true nature of the Foraminifera really commenced, is inaugurated by the discovery, first announced by M. DUJARDIN to the Académie des Sciences in June 1835, of the *Rhizopodous* nature of the animal of certain simple forms of Foraminifera, and, by inference, therefore, of that of the group generally; and in the following year he demonstrated the essential identity between the *Amœba* and other simple freshwater Rhizopods (described by Professor EHRENBERG among the Polygastric Animalcules) and the *Cristellaria* and similar composite forms of marine Foraminifera, which had been previously ranked among Cephalopod Mollusks||.

The general results of M. DUJARDIN'S observations was, that the animal body consists, in every instance, of a mass of *sarcode*,—a gelatinous, somewhat granular substance, not enclosed in a distinct membrane, and capable of extending itself into threads of extreme tenuity; that there is neither mouth nor digestive cavity, but that alimentary particles, received into the very substance of the body, are gradually incorporated with it; and that both the introduction of these particles, and the move-

* Saggio orittographico, overo osservazioni sopra la terra Nautiliche e Ammonitiche della Toscana. Sienne, 1780.

† Testacea microscopica aliaque minuta ex generibus Argonauta et Nautilus, ad naturam picta et descripta. Vindob. 1798, 1803.

‡ Testacea Britannica, or Natural History of British Shells. London, 1803–1808.

§ Conchyologie Systematique. Paris, 1808.

|| See Annales des Sciences Naturelles, 2 sér., Zool. tom. iii. p. 312.

ments of locomotion, are effected by means of pseudopodial prolongations of the *sarcode*, put forth through apertures in the shell, and capable, when retracted again, of coalescing with the general mass. In the case of the composite forms, he considered the entire animal to be made up of a series of segments which are essentially repetitions one of another, each possessing an independent vitality of its own*. These statements have been subsequently confirmed and rendered more precise by several other observers; their truth has been admitted by M. D'ORBIGNY, who, in all his recent works, has described the animals of the Foraminifera in accordance with them (though without any allusion to the fact, that he had himself previously laboured under an entire misconception of their character, and without any mention of the discoverer of their real nature); and they have been recently placed beyond all doubt, by the admirable researches of Professor SCHULTZE (*Op. cit.*).

It cannot but seem surprising, that notwithstanding the light thrown upon this inquiry by M. DUJARDIN in 1835, Professor EHRENBERG should in 1838 have announced to the Academy at Berlin, his conclusion, professedly based on observations of certain forms of these animals in their living state, that their true place in the animal kingdom is among the *Bryozoa*†. He described them as possessing a distinct alimentary canal, which extends from segment to segment; this, however, instead of being single, as in *Nonionina*, may (he tells us) be multiple, as in *Geoponus*; so that we must regard each segment of the latter, however apparently resembling the simple segment of the former, as in reality composed of several adhering bodies. In one instance (he affirms) he found the mouth surrounded by a plumose sensory and prehensile apparatus, like that of the *Flustræ* and *Halcyonellæ* (see *ultra*, ¶ 4.), but generally speaking he admits that this is altogether wanting, the mouth being a simple aperture. He saw minute extensile tentacula proceeding from all parts of the sieve-like shell, as described by DUJARDIN, and admitted their resemblance to the pseudopodia of *Difflugia*, &c., but he remarks, "the rest of their organization, which DUJARDIN has overlooked, removes them from the Infusoria, quite as far as from a chaotic primitive substance." Besides the alimentary canal, Professor EHRENBERG describes a yellowish-brown granular mass as accompanying and sometimes surrounding it up to the last of the spirals; this he considers as an ovary.

As I have reason to believe that Professor EHRENBERG stands quite alone in this opinion (if, indeed, he still maintains it), and that the real nature of the segments of sarcode and of their connecting threads, is no longer a matter of question among those Naturalists who have given their unprejudiced attention to the subject, I do not think it requisite to occupy either time or space with any further discussion of the question, and therefore dismiss it with this brief mention.

* See his "Histoire Naturelle des Infusoires," Paris, 1841; and Art. *Rhizopodes* in Dict. Univ. d'Hist. Nat., tom. xi. p. 115, Paris, 1848.

† See his Memoirs in the Transactions of the Royal Academy of Berlin, for 1839 and 1840; also TAYLOR's Scientific Memoirs, vol. iii. p. 319.

It may, however, be well here to remark *in limine*, that it obviously makes a most essential difference in our appreciation of the value of the characters afforded by the form, position, and multiplication of the apertures of communication between the chambers of the shell, whether we regard these as giving passage to an organ of such fundamental importance as an alimentary canal, or whether they merely serve for the connexion of the different segments by *stolons* of sarcode. For variations, which in the former case must be regarded as indicative of such essential differences, both in structure and function, as would rightly characterize distinct genera or even distinct families, may easily be admitted, on the latter view, to be of such comparatively trivial moment, as to rank no higher than specific characters, or perhaps even to be matters of individual difference. That the latter is the true view of the case, I have become completely assured in the course of my researches; and I shall hereafter be able to adduce some curious illustrations of it.

Turning now to the more recent History of research, I shall briefly notice those investigations which have done most towards the advance of our knowledge of the organization and physiology of the Foraminifera; the mere collection, description, and systematic arrangement of new forms, without any such advance, being no more a feature of progress, than is the building-up of an edifice, which must necessarily fall, through the insecurity of its foundation, before it shall have been completed.

The first series of these, made by Professor W. C. WILLIAMSON of Manchester, upon *Polystomella crispa* *, not only established several important facts in regard to its minute structure, but may be regarded as having furnished the starting-point for all future investigations of a like kind. Among these facts were several that became of essential value to myself, in the inquiry on which I was engaged at the same time, in regard to the structure of *Nummulites*; and served to confirm the inferences which I had deduced from the other features of that important type, as to its participation in the characters of the Foraminifera generally. In the course of that inquiry I made the discovery †, not only of a most elaborate and previously-unsuspected structure in the shell itself, but also of a system of interseptal canals, which established a communication between the inner segments and the external surface, much more direct than that which they possess through the series of segments which form the outer turns of the spire. The existence of this system of canals has been verified, not merely in Nummulites by MM. D'ARCHIAC and HAIME (*Op. cit.*), but also in several recent types; thus Professor WILLIAMSON has detected it in *Amphistegina* and *Nonionina* ‡, and more recently in *Faujasina* § (which furnishes one of the most remarkable examples of it); whilst Mr. CARTER of Bombay has discovered it in *Operculina* ‖. My own inquiries, which have been carried-on with scarcely an intermission, from the time of my first

* Transactions of the Microscopical Society, 1st ser. vol. ii. p. 159.

† Quarterly Journal of the Geological Society of London, vol. vi. February 1850, p. 22.

‡ Transactions of the Microscopical Society, 1st series, vol. iii. p. 105.

§ Ibid. 2nd series, vol. i. p. 87.

‖ Annals of Natural History, 2nd series, vol. x. p. 161.

discovery of this remarkable point of structure, have been specially directed to the determination of the extent to which it presents itself in the different sections of the group, and of its value as a distinctive character; and I think that I shall be able to show that it is a feature of the utmost importance, the presence of which marks an elevation of type, and its absence a corresponding degradation.

It is much to be regretted, that the recent investigations of Professor SCHULTZE should have been so entirely restricted to the structure of the *animal*, which can only be ascertained in a comparatively small number of cases; and that he should have failed so completely in the determination of the internal organization of the *shell**, which in a large proportion of instances is the only guide we possess to the nature of the being which formed it. The new classification which he proposes, whilst in many respects an improvement upon that of M. D'ORBIGNY, is essentially vitiated by this defect; and being in itself, therefore, just as provisional as that for which it is proposed as a substitute, can scarcely be expected to supersede it. My own researches I offer simply as *materials* to serve as a *basis for classification*; feeling assured that the time is not yet come, in which the superstructure can be erected with any prospect of permanent stability.

I shall commence with a minute analysis of one of the lowest types, *Orbitolites*; and propose to show hereafter, that *Orbiculina* and *Alveolina*, though ranked in a different order by M. D'ORBIGNY, are in reality closely allied to it; whilst a new genus (*Cycloclypeus*), which, in M. D'ORBIGNY's arrangement, would rank close to Orbitolites, is physiologically separated from it by the widest possible interval.

Genus ORBITOLITES.

I. *History*.

1. The Orbitolite has been chiefly known, until very recently, rather by its fossil, than by its existing forms. The abundant occurrence of its disks in the *Calcaire grossier* of the Paris basin, early attracted attention; but Orbitolites were not clearly distinguished by the older observers from Nummulites, and their true nature was entirely misunderstood. Thus we find them designated, often in association with Nummulites, under the title of *Umbilicus marinus* by PLANCUS (BIANCHI), who

* Professor SCHULTZE states (*op. cit.* p. 15) his inability to discover the canal-system above described; and as there is no question of his competency and accuracy as an observer, I can only impute his failure to his ignorance of the proper mode of preparing thin sections of these minute shells;—which consists in cementing them to a slip of glass by hardened Canada-balsam; grinding them down as far as may be desirable on one side; then loosening them by heat and turning them over, so that the flattened surface shall now be attached; and finally grinding down the other side, until the requisite degree of thinness shall have been attained; after which a drop of liquid Canada-balsam is laid upon the specimen, gentle warmth applied, and a cover of thin glass put on. Having myself thus prepared sections of *Faujasina*, which answer in every respect to the figures accompanying Professor WILLIAMSON's memoir above cited, I can bear the most explicit testimony to their exactness.

imagined them to be opercula of Ammonites*; of *Porpitæ nummulares* by STOBÆUS† and BROMELL‡, who seem to have regarded them as representing the disks of the existing Porpitæ; of *Helicites* and *Operculites* by GUETTARD §, who considered them as opercula of Gasteropods; of *Discolithes* by FORTIS ||, who supposed them to be skeletons of mollusks; of *Madreporites* by DELUC, and of *Milleporites* by FAUJAS DE ST. FOND, whose idea of their nature is sufficiently indicated by the names they assigned to them.

2. The genus *Orbitolites* seems first to have been erected, and distinctly separated from Nummulite, by LAMARCK, in the first edition of his 'Animaux sans Vertèbres,' its type being the *O. complanata* of the Paris basin. The following is his definition of the genus, which he ranks between Lunulites and Millepora, among his "Polypiers Foraminés":—"Polypiarium lapideum, liberum, orbiculare, planum seu concavum, utrinque vel margine porosum, nummulitem referens. Pori minimi, adamussim dis-positi, conferti, interdum vix conspicui." These bodies, he says, are distinguished from Nummulites by the opening of their marginal pores, and by the absence of spiral arrangement in their minute chambers or cells. In his second edition (1816), he altered the name from *Orbitolites* to *Orbulites*; but the latter designation having been previously employed in Malacology, the first appellation has been restored by M. MILNE-EDWARDS in his posthumous edition of LAMARCK's work. Under one of the designations, *Orbitolites* or *Orbulites*, the genus has been recognized by SCHWEIGGER¶, BRONGNIART and CUVIER**, LAMOUROUX††, DESLONGCHAMPS‡‡, DEFRANCE§§, BLAINVILLE ||||, BRONN ¶¶, GOLDFUSS ***, MICHELIN †††, PICTET ‡‡‡, and DUJARDIN §§§; none of whom, however, have either given any account of its internal structure, or made any essential modification in the definition of the genus, which they all left in the place which LAMARCK had assigned to it.

3. The existence of more than one recent species of the same type was indicated or expressly mentioned by several of the foregoing writers. Thus FORTIS tells us

* De Conchis minus notis, 1739 (*fide* D'ARCHIAC et HAIME), and App. Phytol. F. Coll. 1764 (*fide* RUPERT JONES).

† Dissertatio epist. ad W. GROTHAUS de nummulo Brattenburgensi, 1732; Opera petrefactorum, 1752; Opusculis, p. 6 (*fide* D'ARCHIAC et HAIME).

‡ De Nummulo Brattenburgico, in Act. Litt. Suec., vol. ii. p. 50 (*fide* D'ARCHIAC et HAIME).

§ Mémoires sur différentes parties des Sciences et des Arts, 1770.

|| Mémoires pour servir a l'Hist. Nat. de l'Italie, 1816, vol. ii.; and Journal de Physique, 1801, vol. lii. p.106.

¶ Beobacht. auf Naturg. (1819), pl. 6.

** Ossemens Fossiles (1822), vol. ii. pt. 2. p. 270.

†† Expos. Méthod. des gen. des Polypiers (1821), p. 44. pl. 73.

‡‡ Encyclop. Méthod., Zooph. (1824), p. 584.

§§ Dictionn. des Sci. Nat. (1825), vol. xxxvi. pp. 294, 295.

|||| Manuel d'Actinologie (1830), p. 411. pl. 72.

¶¶ Lethæa Geognostica (1836-37), pl. 35.

*** Petrefacten (1826–33), vol. i. p. 41. pl. 12.

††† Icon. Zoophyt. (1845), p. 167. pl. 46.

‡‡‡ Traité Élément. de Paléontologie (1844–45), tom. iv.

§§§ Dict. Univ. d'Hist. Nat., tome ix. (1847), p. 162.

(*op. cit.*), on the authority of a voyager in the Indian seas, that living Discolites have been found there; and as there are no existing Nummulites, this statement probably refers to an Orbitolite. Lamarck, in his second edition, describes, under the title of *O. marginalis*, a small form of Orbitolite, only 2 millims. (·08 inch) in diameter, found upon fuci, corallines, &c. in the European seas; this he speaks of as the only living example of the genus then known, and he defines it as *O. utrinque plana, margine poroso*. Besides this species, however, Defrance (*loc. cit.*) mentions another, more closely resembling the *O. complanata* of the Paris basin, as existing on the shores of New Holland; and this seems the first clear indication of the body (afterwards found by MM. Quoy and Gaimard in that locality, and erected by them into the distinct genus *Marginopora*), the structure of which constitutes the chief subject of my present communication. Both these existing forms are described by Blainville (*op. cit.*), the first from actual observation, the second on the information of MM. Quoy and Gaimard, to the manuscript of whose 'Voyage de l'Astrolabe' (then unpublished) he refers as his authority. It is singular, however, that after an attentive search through the published "Zoology" of that work, I have not been able to find, either in the text or in the plates, any mention of *Marginopora* or of *Orbitolites*. Of the *Orbitolites marginalis*, M. de Blainville says (*op. cit.* p. 412),—"Nous l'avons étudiée avec soin; et nous sommes presque convaincu que ces petits corps crétacés ne sont pas de véritables polypiers; mais bien quelque pièce intérieure, qui s'accroît par la circonference. Il est en effet évident, qu'il n'y a pas de cellules proprement dites, à moins qu'on ne veuille regarder comme telles les deux plans de locules qui occupent le bord, et qui n'offrent rien determiné. Tout le reste est couvert d'une légère croûte crétacée, qui ferme les anciens pores." I think it obvious, from this description, that it was founded on specimens resembling that in Plate VII. fig. 8, in which the marginal row of cells has been laid open above and below by accidental abrasion; and that the true marginal pores, opening *between* the protuberances formed by the cells (Plate V. fig. 1), were overlooked. The genus *Marginopora*, placed by M. de Blainville in immediate sequence to Orbitolites, is thus characterized (*loc. cit.*):—"Animaux inconnus, contenus dans les cellules poriformes, excessivement petites, rondes, serrées, éparses dans les sinuosités, très fines et tortueuses, qui guillochent la circonference d'un polypier calcaire, libre, un peu irrégulier, discoïde, concave ou concentriquement strié en dessus comme en dessous, et plus épais sur les bords." The two surfaces, M. de Blainville further tells us, only exhibit striæ of increase, without any trace of pores; but the turned-up edge is entirely riddled with very fine rounded pores, which are situated in the sinuosities of a very close but shallow engine-turning (guillochis). And when one of its surfaces is rubbed away, the disk is found to be formed of concentric canals, separated by partitions, and themselves divided into cells, thus recalling in some degree the structure of Orbitolites. Having myself had the opportunity of inspecting, by the kindness of M. Valenciennes, the specimens of Marginopora on which the foregoing

description was founded (these being now contained in the 'Musée d'Histoire Naturelle'), I have been able to compare them with my own; and finding that they correspond with the peculiar type of the latter, which is represented in Plate V. figs. 2 & 3, I have no hesitation in saying that in this description also the *true marginal pores,* represented in Plate V. fig. 6, have been overlooked; and that what are described by M. de Blainville as pores, are nothing else than incomplete cells left open in the frilled edges which bound the marginal furrow above and below (see ¶ 25). A similar description has since been given by M. Dujardin *, who does not hesitate to regard the disk as a polypary, and to speak of the animals whereby it is formed, as polypes.

4. In the Memoir of Professor Ehrenberg already referred to, we find the genus *Orbitolites* for the first time associated with true Foraminifera, as a member of his class Bryozoa, order *Polythalamia,* suborder *Polysomatia,* family *Asterodiscina,* wherein it is placed next to *Lunulites,* which undoubtedly belongs to the group of Bryozoa (Polyzoa) as now restricted. This family he characterizes as follows:—"Gemmis in eodem plano prodeuntibus, polypiaria plana, discoidea, formantibus, osculis distinctis post mortem apertis;" and it is by the last of these characters that he distinguishes it from the family *Soritidæ,* consisting of the two genera *Sorites* and *Amphisorus,* of which he says,—"Osculis contracto corpore, tanquam operculo duro clausis." If any faith whatever is to be placed in Professor Ehrenberg's figures and descriptions, his *Sorites* is nothing else than Lamarck's *Orbulites marginalis*; whilst his *Amphisorus,* which differs from *Sorites* merely in having two layers of cells instead of one, is (as I shall hereafter show) the same type in a higher grade of development. I cannot conceal my astonishment, however, that so practised a microscopic observer should have entirely overlooked the real marginal openings between the cells; still more, that he should have described the entirely-closed cells of the surface as covered in by a moveable operculum, which merely shuts their orifices when the animal is contracted; and further, that, mistaking an accidental for a normal opening of some of the cells, he should have ventured to figure an eight-armed Bryozoon as issuing forth from one of them,—a phenomenon which, I do not hesitate to say, is entirely irreconcileable with our existing knowledge of the organization of the animal of which these disks are the skeletons.

5. The earlier publications of M. d'Orbigny on the subject of the Foraminifera do not include any notice of this genus; and neither in the systematic arrangement which he put forth in his article in the 'Dict. Univ. d'Hist. Nat.' tome v. (1844), nor in that contained in his 'Foram. Foss. de Vienne' (1846), is the order *Cyclostègues* recognized, which makes its appearance for the first time in his 'Cours Elémentaire de Paléontologie,' tome ii. (1852), between the Monostègues and the Helicostègues, with the following definition (p. 192):—"Animal composé de segments nombreux, placés en lignes circulaires. Coquille discoïdale, composée de loges, concentriques,

* Dict. Univ. d'Hist. Nat., tome vii. p. 777.

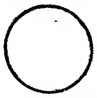
simples ou multiples; point de spirale." Under this order are ranged the genera *Cyclolina* (D'ORB. 1839), *Orbitolites* (LAMARCK, 1801, and *Marginopora,* QUOY et GAIMARD, 1836), *Orbitolina* (D'ORB. 1847), and *Orbitoides* (D'ORB. 1847). As I shall have occasion to show that the first three of these genera cannot be separated from each other by any valid distinctions, and that the greater number of the species ranked under them by M. D'ORBIGNY (see his 'Prodrome de Paléontologie Stratigraphique') really belong to the same specific type, I must here cite the generic characters which he assigns to them:—"*Cyclolina,* Coquille discoïdale, chaque loge percée de nombreux pores, faisant un circle entier autour des autres. L'espèce connue est de l'étage cénomanien.—*Orbitolites,* Coquille discoïdale, plane, égale, et encroûtée des deux côtés, pourvue de lignes concentriques. Loges nombreuses, par lignes irrégulières, transverses, visibles seulement au pourtour. Nous connaissons deux espèces; les premières, de l'étage suessonien; le maximum, dans les mers actuelles.—*Orbitolina,* Ce sont des Orbitolites à côtés inégaux; l'un, convexe, encroûté, à lignes concentriques; l'autre, concave, non encroûté, montrant des loges nombreuses, par lignes obliques sur le côté, au pourtour. Nous connaissons de ce genre perdu six espèces; les premières, de l'étage albien; les dernières, de l'étage senonien."

6. The first approach towards a more accurate knowledge of the real nature of the Orbitolite, through an examination of its internal structure, was made (I believe) by myself, in my Memoir "On the Microscopic Structure of *Nummulina, Orbitolites,* and *Orbitoides,*" read before the Geological Society of London in November 1849, and published in its Quarterly Journal for February 1850. The place assigned to this genus in the system of M. D'ORBIGNY not having been at that time made public, and all other zoologists and palæontologists having ranked it in close approximation to *Lunulites* and other Polyparies of the Bryozoic (Polyzoic) kind, I entered upon the examination without the least suspicion that this organism was to be regarded in any other light; and that I was not undeceived in the course of it, may be attributed to the small number of specimens then placed at my disposal for the inquiry by my late friend Professor E. FORBES, and to the circumstance that these specimens were of the type that presents most resemblance to that of a Bryozoic polypary, and were all deficient in the central nucleus, which is the portion most indicative of their Foraminiferous nature. Nevertheless, the marked dissimilarity in structure which I found to exist between the disk of Orbitolite and the polypary of Lunulite or of any other undoubted members of the Bryozoic group, made me even then express myself doubtfully as to its title to be associated with them. In this Memoir, published two years previously to M. D'ORBIGNY's first announcement of the fact, I showed that the genus *Marginopora* must be abolished, since its sole representative is so closely allied in structure to the *Orbitolite* of the Paris basin, that no doubt of their generic identity can be entertained; the existing *M. vertebralis,* in fact, being only specifically distinguishable from the fossil *O. complanata,* by a difference in the form of its super-

ficial cells,—a character to which the more extended knowledge of this type has made it clear to me that not the slightest value is to be attached (see Sect. IV.). I showed that in one as in the other, the cells are normally closed-in over the whole surface; that the cells of the two surfaces are separated from each other by an intervening stratum, traversed by a set of round cells or passages of its own, with which each superficial cell communicates by two small apertures; and that the only real external orifices are the minute pores at the margin of the disk, which communicate, not directly with the cells of the superficial layers, but with the passages of the intermediate stratum.

7. A very important addition to this limited measure of information was made not long afterwards by Professor WILLIAMSON of Manchester, who, in a paper read before the Microscopical Society of London, June 12, 1850, and published in its Transactions (First Series, vol. iii. March 1851), first gave a minute description of the small recent *Orbitolites marginalis* of LAMARCK (which, however, he designated as *O. complanata*); contrasted it with that of a large recent Orbitolite from Tonga, shown by his description to be identical with the *Marginopora* of QUOY and GAIMARD, to my previous account of which he added some important particulars; and compared both with the well-known *Orbiculina adunca* of the Bahamas. His investigations led him to the conclusion, that these three forms should rank under the same genus *Orbiculina*; their most important structural features being common to all, whilst their differences are only of specific value. His *Orbiculina complanata* (really *Orbitolites marginalis*) he characterizes by its spiral commencement, and by its possessing only one layer of cells; his *O. Tonga* (Marginopora) he characterizes by its cyclical commencement, and by its possession of two superficial layers of cells, with an intermediate stratum, as I had previously pointed out; whilst the *O. adunca* he shows to commence on the spiral type, and to carry it on much further than his *O. complanata*, but finally to assume the cyclical, and then to correspond very closely with his *O. Tonga*. The title of the genus *Orbitolites* to a place in the group of Foraminifera, in near proximity to, if not in union with, *Orbiculina* (which had been ranked as such by M. D'ORBIGNY from an early period of his investigations), and the entire absence of any ground for ranking it among the Bryozoa (Polyzoa), were clearly established by Professor WILLIAMSON in this valuable memoir; and though I shall hereafter have occasion to show that some of his conclusions were erroneous, yet I regard them as fully justified at the time, by the information which the materials at his command afforded; my own means of correcting them being only supplied by the comparison I have been enabled to institute through a much wider range of specimens. And it is with great satisfaction that I am enabled to add, that, after a careful inspection of my preparations and drawings, Professor WILLIAMSON authorises me to express his full accordance in the results which I shall now proceed to detail.

8. As the value of such details cannot be truly estimated without some knowledge of the range of the observations from which they are derived, I think it right to state

in limine what are the opportunities I have enjoyed. The first and most important of these was afforded me by the great abundance of Orbitolites of various sizes, from ○ to , besides a vast multitude of fragments, in Mr. JUKES's Australian dredgings; besides which, Professor E. FORBES kindly put into my hands several specimens which had been taken in their living state by Mr. JUKES, from the marine plants to which they were attached. All these I have carefully examined under the microscope, so as to be able to make an exact determination of their external characters; and of a large proportion I have made microscopic sections in various directions, that I might assure myself of every particular respecting their internal structure. When I had nearly exhausted these sources of information, I found a new and most interesting series of specimens in Mr. CUMING's Philippine collection; and by the study of these I was enabled to test the validity of the conclusions, to which I had been led by the examination of the Australian forms. The kindness of various friends has further enabled me to examine specimens obtained from other widely-distant localities, such as different parts of the Indian, Southern, and Pacific Oceans, the Red Sea and the Ægean. And finally, I have had placed at my disposal, through the instrumentality of Professor QUEKETT, several Orbitolites of various sizes and ages, obtained on the shores of the Feejee Islands by the late Sir EVERARD HOME, in which the animal substance occupying the interior had been preserved by the immersion of the fresh specimens in spirits.

9. Besides the existing forms, I have examined a large number of specimens of *Fossil Orbitolites*, both from the Paris basin and from other localities; and I have instituted the same kind of minute comparison of these specimens, both with each other and with the recent types, that I had previously made among the diversified forms of the latter.

10. Postponing, until adequate means shall have been supplied by the details of their organization, to be presently given, the inquiry into the relationship of these different forms (Sect. VI.), we shall proceed in the first place to consider the general plan of organization of the Orbitolite, and then to study the variations to which this is subject.

II. *General Plan of Organization.*

11. In studying the organization of the Orbitolite, we shall have recourse, on the one hand, to the structural characters presented by the *Animal*, as displayed by the fleshy residuum left after the decalcification of specimens in which it has been preserved; and on the other, to the structural characters presented by the *Shell*, of which some are visible on its surface, and without any preparation, whilst others may be seen in thin specimens by transmitted light, but of which the greater part can only be brought into view by thin sections taken in various directions, especially *horizontal* or parallel to the surface, and *vertical* or perpendicular to the surface.

12. The state of preservation of the animal body of the Orbitolite, in the spirit-specimens which I have examined, is so complete, as to leave me no room for hesitation in affirming that it corresponds in every particular with the 'sarcode' which we have seen to have been first described by M. DUJARDIN, as constituting the bodies of many of the lowest organisms, and especially as the component of those of the Rhizopoda. A small portion of this substance, sufficiently magnified to exhibit its nearly homogeneous jelly-like aspect, with minute granules and somewhat larger particles scattered through it, is shown in Plate IV. fig. 2. Although it is so far decolorized in spirit-specimens as to present only a brownish hue, yet as specimens that have been gathered fresh and have been then dried, possess a reddish aspect, and as this is not due to the shelly substance, it may be presumed that the sarcode of the living Orbitolite has the same bright red colour as that of *Rotalia* and many other Foraminifera. The entire animal body (Plate IV. fig. 1) is composed of a numerous assemblage of minute segments, arranged at tolerably regular intervals in concentric zones around a sort of central 'nucleus;' the segments composing each zone being united with each other by a continuous annular 'stolon' or band of sarcode, and being connected with those of the adjoining zones by peduncles of the same material. I have not met with the least indication that the sarcode is contained within any *proper membrane*; and the absence of any such indication, notwithstanding the various manipulations to which I have subjected its segments, may be taken, I think, as strong negative evidence that it has no more existence in this animal, than it has in the species of Foraminifera which have been so well studied by M. DUJARDIN and Professor SCHULTZE. Nor is there the slightest trace of distinct *organs*, either in the mass of sarcode which forms the central nucleus, or in that which constitutes each one of the surrounding segments; and he would, I think, be a mere speculator, who should maintain the presence of a digestive cavity in any of these parts, or the existence of an intestinal canal in the peduncular threads which connect them together. The homogeneity of the component substance of the central nucleus, and of the entire assemblage of multiple segments, seems, indeed, to be conclusively established by the following facts:—In all the spirit-specimens which I have examined, the cavities of the outer zones are completely void, whilst those of the nucleus and of the inner zones are quite filled with their animal contents. This drawing-together of the soft body towards the centre, is evidenced also in many of the larger specimens which have been dried when collected in the living state, by the limitation of the red colour that indicates the presence of the sarcode, to the inner portion of the disk. In both cases it may be presumed that the animal matter has shrunk together, in the former through the corrugating action of the spirit, in the latter through desiccation. Now if the polypidom of a zoophyte be similarly treated, there is no such drawing together of the entire body, but each cell is found to contain the shrunk contents of its own polype-segment; and this difference seems to me to indicate a complete dissimilarity in the characters of the two organisms. For it is obvious that the sub-

stance of the peripheral segments of the Orbitolite-body can only be brought together towards the centre, through being completely unattached to the walls of the cavities which it occupies, and through having a form so alterable, as to be capable of being drawn in threads through the narrow connecting passages, and of then coalescing together again so perfectly, that the masses they form do not present the least trace of having been thus spun out. There is no known kind of animal texture, except *sarcode*, that is susceptible of this kind of alteration; and the evidence of it which I have adduced seems to me extremely valuable, not only as establishing the general nature of the animal body of the Orbitolite, but also as fully justifying the assumption, that, in the living state, the sarcode is projected in pseudopodia through the marginal apertures, and that alimentary particles are introduced by their instrumentality, as in other Foraminifera.

13. Turning from the animal body to the calcareous disks which enclose it, we find that, whether large or small, these are almost invariably circular, or nearly so; that they are usually nearly flat, any difference in thickness being generally in favour of the marginal portion; and that if, as sometimes happens, there is a slight central projection, this is formed by the nucleus alone. By these characters we may distinguish *Orbitolites* from *Orbiculina*; for although the discoidal forms of the latter so strongly resemble Orbitolites, that by the structure and arrangement of their marginal portion they could not be distinguished, yet they may always be discriminated by the knobby protuberance of their centre, which is occasioned by the mutual investment of the earlier whorls of the spiral in which they commence. The same entire absence, or very small size, of the central elevation, together with the uniformity or even slight increase of thickness towards the circumference, also helps us to separate *Orbitolites* from *Orbitoides*; the centre of the latter being always considerably elevated, and the thickness of its disk ordinarily diminishing gradually towards its margin *. Around the 'nucleus' which occupies the centre of the disk (Plate V. figs. 1, 6), are seen an indeterminate number of concentric zones of cells (c, c, c), the shape of which differs in different individuals (see Sect. IV.); these, although completely closed (unless laid open by abrasion), have their form

* I wish this statement to be understood with reference to the genus *Orbitoides*, as characterized by the structure which I have shown it to possess (Quart. Journ. of Geol. Soc., Feb. 1850), and not to the genus as defined by M. D'ORBIGNY (Cours Élémentaire de Paléontologie, tome ii. p. 194), who, notwithstanding that he has shown himself to be acquainted with my Memoir (by copying from it a figure of Nummulite), has not profited in any degree by my investigations, but has left the generic characters of *Orbitolites*, *Orbitolina* and *Orbitoides* in the state in which they might have been, and probably were, before that Memoir was published. The true distinction, however, has been fully recognized by M. D'ARCHIAC, who, in his 'Description des Animaux Fossiles du Groupe Nummulitique de l'Inde,' p. 349, has designated as *Orbitoides dispansa* and *Orbitoides Fortisi*, the bodies which, in the account of them he had previously given in the 'Mém. Soc. Géol. de France,' 2nd ser., vol. iii., he had designated as Orbitolites; thus correcting the error into which Mr. CARTER has fallen in his description of the same fossils, through reliance on M. D'ORBIGNY's insufficient and indeed erroneous characters of these genera.

distinctly indicated by the surface-markings. The only external orifices which communicate with these cells, are the minute pores (*d*, *d*, *d*) forming one or more ranges at the margin of the disk, each pore lying in a vertical furrow, between the projecting walls of two contiguous cells. In the smallest and thinnest disks (Plate V. fig. 1) we find but a single row, or sometimes two rows, of such pores; in disks somewhat thicker, there are three or four rows; and in the largest and thickest Orbitolites (Plate V. fig. 6), no fewer than ten or twelve such rows. This multiplication in the number of ranges of marginal orifices, indicates a like multiplication in the number of floors (so to speak), of which the disk is composed; and just as the total number of chambers in a building may be increased, either by extending its base over a larger area, or by additions to its number of storeys, so may an increase in the number of segments of which this animal is composed be provided for, either by the marginal addition of a new zone resembling the last, so that the diameter of the disk is alone augmented, or by an increase in the thickness of the newly-forming zone, so that it contains a larger number of superposed layers. The new zones, however, *never invest* or cover those which they surround, each being simply a continuation of the margin of the preceding; and in this respect the mode of growth of *Orbitolites* at every stage is pointedly distinguished from the early mode of growth of *Orbiculina,* just now specified as the cause of the protuberance of its centre.

14. The shelly *substance* of the calcareous disk, although firm, is by no means so dense and bony as that of the shells of many other Foraminifera of higher organization. It is apparently quite homogeneous, rarely presenting the least appearance of 'structure,' and this being probably fallacious; I refer to the punctated marking sometimes seen on the outer surface of the nucleus, which shows itself under the aspect represented in Plate VI. fig. 5, when the thin layer of shell which presents it is viewed by transmitted light. Although this appearance might be considered to indicate the existence of a cellular structure in the shell, yet I believe that such an inference would be fallacious; since I have not been able to detect the least trace of such a structure in the decalcified residuum, which, on the other hand, seems to me to be a substance as structureless as sarcode itself. Coupling these appearances with those which I have found to exist more distinctly in *Orbiculina,* I am disposed to interpret them as proceeding from minute *depressions* on the surface; and these are perhaps to be regarded as the rudiments of those minute closely-set apertures, which, in many Foraminifera, give passage to pseudopodial extensions of the sarcode from every part of their bodies.

15. In all the forms of Orbitolite that I have examined, the central *Nucleus* presents the same essential characters. When the interior of any disk, whether large or small, is laid open by a horizontal section passing through the central plane, the nucleus is seen to be occupied by a large cavity (Plate V. fig. 1) somewhat irregularly divided by a sinuous partition, which always, however, marks out a central

cell (*a*) of a somewhat pyriform shape, as distinct from the space (*b*, *b*) which surrounds it. The meaning of this feature is at once made apparent, by reference to the disposition of the sarcode which occupies the cavity of the nucleus; for we then see (Plate IV. fig. 5) that the large central pear-shaped cell is occupied by a mass (*a*) of corresponding shape, from the small extremity of which a peduncular process extends, that dilates again into a still larger mass (*b*, *b*) completely surrounding that from which it springs; the former may be conveniently designated as the 'central,' the latter as the 'circumambient' segment. In a *vertical* section of the disk, passing through the centre, such as that seen in Plate V. fig. 4, the nucleus seems to present *three* chambers; but this is simply due to the fact that such a section will traverse the circumambient cell twice, that is, will cut it through on both sides of the central cell. In the section represented in Plate V. fig. 9, there are but *two* central chambers; in this case the plane of division seems to have traversed the nucleus just where the neck of the central cell touches its margin, so that the circumambient cell is only on one side of it. If, on the other hand, the plane of division should happen not to pass through the central cell at all, so as to traverse the circumambient cell alone, a *single* broad cavity will present itself in the vertical section, as shown in Plate V. fig. 7. Frequently, however, it happens that the circumambient segment is partially subdivided on one side by an interposed partition (Plate VII. fig. 4); and then a vertical section will show *four* chambers, as is seen in Plate V. fig. 10, the central segment having a single portion of the circumambient segment on one side of it, and a double portion on the other. Some remarkable varieties in the size of the nucleus, and in the mode of its connexion with the surrounding parts, will be noticed hereafter (¶¶ 44–46, and 54, 55).

16. In describing the structure of the *Concentric Zones* which successively surround the nucleus, it will be requisite to make a distinction between the *simple* and *complex* types according to which the Orbitolite-disks may be generated; the former being characterized by the existence of only one layer or 'floor' of segments, the latter by the presence of *two or more* such layers. For although, as will subsequently appear, I can show, by a series of transitional gradations between these two types of structure, and by their occasional coexistence in the same *individual*, that they are not to be held to characterize distinct *genera* (as Professor EHRENBERG supposed), or even distinct *species* (as Professor WILLIAMSON has urged with more apparent reason), yet, when most characteristically displayed, they differ so much from one another, and each is so remarkably distinguished by features of its own, that it seems more advantageous to describe them separately in the first instance, and then to discuss their relationship to each other.

17. The *Simple* type is found to prevail in those minute Orbitolite-disks, which occur in greater or less abundance in sands and dredgings from almost every part of the globe, but which are particularly numerous in those of the Philippine shores. Their ordinary diameter is about ·05 of an inch, and they usually contain from ten

to fifteen concentric zones. The arrangement and connexions of these zones may be made out in the thinnest and most translucent specimens, by examining them by transmitted light, after mounting them in Canada balsam; this, however, gives such transparence to the thin shelly layer which is continuous over both surfaces, that it may escape notice (if not carefully looked for), so as to lead to the conclusion that the cells are open. Most specimens require to be somewhat reduced in thickness, by slightly grinding down one surface, to enable the arrangement of their interior to be distinctly made out; and this may be examined either by transmitted or by reflected light. Each zone thus seen in horizontal section (Plate V. fig. 1, *c*, *c*), consists of a circular set of small ovate cells, excavated, as it were, in the shelly substance of the disk, and communicating with each other laterally by passages which unite them together into a continuous annulus. The zone which immediately surrounds the nucleus is connected with it by passages which extend from the outer margin of the large circumambient segment to the several cells of which it is itself composed; and each zone communicates with the one on its exterior by similar passages, which usually extend, however, not from the *cells* of the inner zone to those of the outer, but from the *connecting passages* of the inner zone to the cells of the outer (Plate IV. figs. 8, 9); and thus it comes to pass, that the cells of each zone usually *alternate* with those of the zones that are internal and external to it. A vertical section of the disk, such as is shown in Plate V. figs. 4, 5, exhibits the same arrangement under a different aspect. The cells of the concentric zones are seen to be much higher than they are broad, so that they present a somewhat columnar form; the proportion of their height to their breadth, however, may vary greatly in different parts of the same disk, the former often increasing from the centre towards the periphery (fig. 4), whilst the latter remains constant, or nearly so; and the columns, instead of being straight, are generally more or less curved, and are sometimes bent in the middle at an obtuse angle (Plate V. fig. 7, *a*, *b*). The gradation which presents itself from one of these forms to the other, and their coexistence even in the same specimens, clearly proves that no value can be attached to the form and proportions of the cells, thus seen in a vertical section, as furnishing specific characters. In every perfect specimen, the columnar cells are seen to be closed at their two extremities by a thin shelly wall; and this is sometimes flat, sometimes more or less convex *.—The meaning of these arrangements is clearly seen, when we turn our attention to the structure of the animal (Plate IV. fig. 1). For the outer margin of

* In a large proportion of the specimens obtained from sands or dredging, the cells have been laid open by attrition; either throughout the surface of the disk, if it should be flat, or at its margin only, if it should be at all saucer-shaped. The constancy of this last character in a certain set of forms, resembling that represented in Plate VII. figs. 8, 10, might at first sight lead to the idea that they constitute a distinct specific type; but, as will hereafter appear, these plate-shaped disks cannot be separated by any definite line of demarcation from such as are quite plane; and in specimens of them which have not suffered attrition, the marginal cells are closed, like all the rest.

the circumambient segment of the nucleus is seen to give off a number of slender prolongations or 'stolons' of sarcode, which radiate from it to a short distance and then enlarge into columnar segments having a circular or ovoidal base, which are united with each other laterally by an annular 'stolon'; and from the portions of this 'stolon' which intervene between the segments of each annulus of sarcode, are given off the radiating 'stolons' that go to originate the next zone, the arrangement of whose parts is precisely similar to that just described.

18. In this manner, any number of concentric zones may be formed, which are exact repetitions of each other, except that the number of segments in the outer zones is greater than that of which the inner zones are composed. It does not increase, however, in the regular ratio of the respective diameters of the zones; for the cells of the outer zones, being usually both larger and more widely separated from each other than are those of the inner, are less numerous in proportion; thus in a specimen before me, there are twenty-eight cells in the innermost row and only forty-nine in the outermost, though the latter is more than twice the diameter of the former. The increase in the number of the segments is accomplished by the occasional *interpolation* of an additional segment, communicating directly with the one immediately interior to it, between the two segments which spring from the annular stolon on either side of the latter, as is shown in Plate IV. figs. 8, 9, *a*. Hence it is obvious that prolongations of sarcode giving origin to new segments, although ordinarily put forth rather by the connecting 'stolons' than by the segments themselves, may originate from any part of the annulus. This is shown still more forcibly by the occasional occurrence of irregularities, such as that represented in Plate VI. fig. 6.

19. The cells of the last-formed zone communicate with the exterior by the very same kind of radial passages, as in other instances communicate with the next zone; and the external orifices of these form the pores which present themselves at the margin of the disk (Plate V. fig. 1). Thus it is seen, on the one hand, how it happens that these pores are intermediate between the cells, instead of opening directly into them; and on the other, how each pore leads, by the divarication of its passage, into two cells, one on either side of it. When a new zone is formed, each pore opens into one of its cells; and this zone in its turn communicates with the exterior, through a new set of pores at its own margin. Each pore is often surrounded by a rather prominent annulus of shell (Plate V. fig. 1, *d*); and it is obvious that when the section passes through this, it will be indicated by a little 'beak' on either side of the entrance to the passage; such 'beaks' (which are of course repeated through the entire disk) are shown in their ordinary aspect in Plate IV. fig. 9, but they are frequently more prominent, as is shown in Plate VI. fig. 1.

20. In all cases in which the growth of the disk takes place with normal regularity, a *complete circular zone* is added at once. Exceptions to this regularity are rare, and they can be generally traced with probability to some accidental interruption. It can scarcely be doubted, I think, that when a new ring of cells is about to

be formed, the prolongations of sarcode issuing from the several pores of the preceding zone coalesce, so as to form a complete zone of segments and connecting stolons around the margin of the previously-formed disk; and that the deposit of calcareous matter forming the shelly walls of the cells and passages, takes place *upon,* or rather *in,* the superficial portion of this zone of sarcode. But I cannot find any evidence in the ordinary growth of the disk, that the sarcode extends itself over the surface of the portion previously formed; although occasional appearances will be hereafter described (¶ 53), that seem to indicate that it *may* do so.

21. It is a fact of much importance in the due appreciation of the relations of *Orbitolite* and its allied forms to other tribes of Foraminifera, that the calcareous partition which separates each cell of any one zone from its neighbours on either side, is not double, but *single.* And this is in great part the case, even with regard to the partitions that separate the cells of successive zones; the inner or central boundary of one being chiefly formed by the peripheral wall of the other. It is not easy even in thin *sections* to distinguish the boundary between the walls of one zone and those of another, so absolutely continuous do they appear to be. But it not unfrequently happens, that in *fracturing* these disks, their component zones come apart from each other, along their natural lines of junction, so as to disclose the real inner (or central) margin of the outer segment, which then presents a set of wide apertures, through which we look at once into its cells; thus proving their incomplete enclosure by proper walls on that side (Plate V. fig. 1, *ff*). Thus in the formation of each new zone, the calcareous envelope seems to be only generated where the sarcode is not already in contact with a solid wall.

22. There cannot be any reasonable doubt, that the number of concentric zones which any disk may present, is entirely determined by its stage of growth, and that it affords no basis whatever for specific distinction. Just as in the case of the concentric layers of wood in the stem of a tree, a minute nucleus, surrounded by only a single annulus of cells, may come in time to be the centre of a large disk consisting of many scores of concentric zones. Although, as already stated (¶ 17), most of the Orbitolites formed upon this simple type are of comparatively small size, yet there does not seem to be any definite limit to the multiplication of zones; for I possess specimens attaining ·15 of an inch in diameter, and consisting of about forty zones (much larger, therefore, than the younger zones of the complex type), in which there is no appearance of any departure from the original mode of growth. That comparatively few specimens, however, attain so large a size upon this simple type of structure, is due, I believe, to the circumstance that they early tend to develope themselves upon the more complex plan which I shall presently describe.

23. Although I have spoken of these disks as typically plane or nearly so (there being usually no great difference between the thickness of their central and that of their peripheral parts), yet it not unfrequently happens that the successive zones gradually increase in thickness from within outwards (as is shown in Plate V. fig. 5),

so that the height of the columnar segments progressively increases, and the entire disk becomes somewhat biconcave. Sometimes, again, without any alteration in the thickness of the several parts, the disk comes to assume, by the depression of its central portion, the shape of a plate, or that of a watch-glass, or (by the more complete upturning of its edges) that of a saucer. In any case in which either surface of the marginal zone is more exposed by its projection than those of the zones which it encloses, there will be a special liability to a laying-open of its cells (as shown in Plate VII. figs. 8, 10) if the disk should be subjected to attrition; and I believe that not only the recent species *O. marginalis*, but the fossil *O. macropora*, are nothing else than examples of this type, the figure of the latter given by GOLDFUSS * corresponding exactly with a form of it which I have frequently encountered. I have not met with any examples in this simple type, of that marginal thinning away as age increases, which is observable in many other Foraminifera.

24. From the simplest, it will be convenient to pass at once to the *most complex* type of structure presented by the Orbitolite, the existence of which is marked (as already noticed, ¶ 13) by a multiplication of the horizontal ranges of marginal pores. I have met with this form in specimens obtained by dredging, from the coast of Australia, from various parts of the Polynesian Archipelago, from the neighbourhood of the Philippine Islands, from the Red Sea, and from the Ægean; and as the sands of all these localities present the simpler type in great abundance, I am disposed to believe that the former is really not the less widely diffused than the latter, and would be discovered wherever it abounds, if properly searched for. The largest specimen in my possession, measuring seven-tenths of an inch in diameter, is from the coast of Australia, where these Orbitolites are so abundant at certain spots (as I learn from Mr. JUKES), that their entire disks and fragments, with fragments of Corallines (chiefly, I believe, the *Corallina palmata* of ELLIS), constitute the great mass of the dredgings. Among the Australian specimens, several attain a diameter of ·45 inch, and a considerable proportion as much as ·30 of an inch. Hence the Orbitolites of this type are among the largest forms of existing Foraminifera, being only surpassed, as far as I am aware, by the Cycloclypeus hereafter to be described. Of two specimens in my possession from the Feejee Islands, one measures ·63 inch, and the other ·53 inch in diameter; but the average of the Polynesian specimens, like that of the Philippine, Red Sea, and Ægean, seems to be considerably lower than that of the Australian, as their diameter seldom exceeds ·25 of an inch, and is usually not more than ·10 or ·12.

25. The disks formed on this plan, like the preceding, may be considered as typically circular, although they are seldom or never exactly so in reality. They may be considered, too, as typically flat, with a slight concavity in the central part, from which, however, the nucleus often projects; but, as will hereafter appear, there is no constant relation either between the thickness and the diameter of different specimens,

* Petrefacta, pl. 12. fig. 8.

or between the thickness of different parts of the same specimen, and the distance of these parts from its centre. The only remarkable departure from the ordinary form which I have met with, presents itself in certain Orbitolites from the Feejee Islands, of which several specimens in the Museum of the Royal College of Surgeons, and two in my own possession, exhibit a curious plication towards their margins; the degree of this departure varies so much, however, in different individuals, the plication being almost obsolete in some (see Plate V. figs. 2, 3), that it cannot be admitted to mark a specific diversity; and considering that these disks always grow on the surfaces of other bodies, it can scarcely, I think, be considered improbable, that the plications originate in the inflections of those surfaces *. These same specimens, moreover, also exhibit another curious abnormality; namely, the projection of the upper and lower edges of the margin, so that a groove is left between them, the projecting laminæ being thin and foliaceous, and their cells very irregularly arranged. This peculiarity, again, being far from uniform in its degree, and being altogether wanting in specimens which in other respects precisely resemble those with plicated and foliated margins, must be considered merely in the light of an accidental variety; but I cannot suggest any explanation of its occurrence, or of its limitation (so far as I am aware) to this particular locality.

26. The surface of the disk (Plate V. fig. 6) is marked out, as in the simpler type, by concentric zones of cells, the number of which bears a general (though not a constant) ratio to its diameter; these cells are usually somewhat rectangular in shape and sometimes approach a square, but are more commonly nearly twice as long in the line of the radius of the disk as they are in the transverse direction, their long sides being parallel to each other. We shall hereafter see, however, that the form of the superficial cells is very subject to variation, and that it may be very dissimilar even in different zones of the same disk (¶¶ 48–52). The pores at the margin of the disk are disposed, as in the simpler type, between the projections formed by the convexities of the cells; and each is usually surrounded by the projecting annulus formerly noticed (¶ 19). The disposition of these pores, however, is far from regular, as they seldom form rows that seem exactly continuous with each other, either horizontally or vertically; and the number of pores in each vertical row is by no means constant, even in different parts of the margin of the same disk †.

* I have elsewhere noticed the fact, that various species of *Orbitoides* are disposed to exhibit a like contortion; and that the well-marked *ephippial* shape which some specimens present, is nothing else than an accidental variety (see Quart. Journ. of Geol. Soc., vol. vi. pp. 34, 35).

† In following the description of the internal structure of this type of Orbitolite, it will be convenient for the reader to make frequent reference to the ideal representation which has been built up in Plate V. fig. 6, by the combination of materials furnished by a great number of preparations which are represented in separate figures accompanying the original Memoir in the Archives of the Royal Society; these last of course furnish the real authority for every point in the description, the ideal figure, however, serving to display the relation of different parts to each other in a manner that no single preparation would possibly admit.

27. The disks of this complex type are not distinguished from those of the simple type already described, by any difference in the structure of the Nucleus; and there is frequently nothing specially characteristic in the structure of the zones that immediately surround it. Each of the peripheral zones, however, consists of two *superficial* layers, an upper and a lower, and of an *intermediate* stratum;—these will now be described *seriatim.*

28. The *superficial* layers are formed of the (usually) oblong cells, whose contour is indicated by the surface-markings; when they are laid open horizontally, by rubbing away the thin shell which covers them in (Plate VI. fig. 3), it is seen that the floor of each cell has an aperture at either end; but no communication can be traced, either through the side-walls between the contiguous cells of the same zone, or through the end-walls, between the cells of successive zones. Moreover, there is no such alternating arrangement of the cells of successive zones, as we have seen to prevail in the simpler type (¶ 17); and they altogether seem to be quite independent one of another. When this superficial layer is examined in a vertical section having a radial direction (Plate VI. fig. 7), it is seen that the floors of its cells (a, a) are formed by the expanded summits (d, d', d'') of the irregular septa, which separate from each other the columnar cells of the intermediate stratum ($c\ c\ c\ c$); and that the apertures at the two ends of the floor are the entrances to passages (e, e', e''), which lead obliquely downwards (the passages on either side of the partition between two successive cells of the *superficial* layer inclining towards each other) towards these cavities. It is observable, moreover, that just at the point at which the contiguous passages meet each other, there is always a round aperture (f, f', f'') in the partition (g, g) which divides the contiguous cells of each zone; and when, in a horizontal section, the superficial cells have been entirely ground away, so as to lay open the most superficial part of the intermediate stratum, this part is found to be traversed in each zone by a continuous circular canal (Plate VIII. fig. 3), with large rounded openings that lead into the columnar cells beneath. The meaning of this arrangement becomes obvious, when we examine the disposition of the animal substance which occupies these cavities; for we find, as might have been anticipated, that the superficial cells are filled with segments of sarcode of corresponding shape (Plate IV. figs. 4, 7, *aa*); and that whilst these have no direct connexion with one another, each of them is connected by means of fleshy peduncles with the annular stolons *bb* that run along its extremities; whilst from the under side of these annular stolons (fig. 4) descend the thick columns of sarcode (cc, $c'c'$), which occupy the columnar cells of the intermediate stratum. The absence of any essential dependence of the segments of the *superficial*, and of those of the *intermediate* strata upon each other, seems indicated by the fact that there is no constant numerical relation between them,—a circumstance which extremely perplexed me, until I had ascertained, by examination of the animal, that the passages (Plate VI. fig. 7, e, e', e'') debouch, not (as I had at first supposed) into the columnar cavities, but into the annular canal,

which serves to bring the superficial and columnar segments of each zone into mutual communication.

29. As the description now given of the superficial layer applies equally to both surfaces, we may now proceed to the *intermediate* layer. When this is laid open by a horizontal section (Plate V. fig. 6), it is seen to consist of a series of concentric zones, the cells of which *alternate* with each other, like those of the simpler type (¶ 17.). The cells are usually circular (or nearly so) in form; but seem to differ considerably in size, even in different parts of the same zone. Their borders, however, very commonly present a funnel-like aspect; and thus we perceive that the diameter of the cavity is liable to vary, according to the part of it which the section happens to traverse,—a fact which becomes more obvious when *vertical* sections are examined; for it is then seen (Plate VI. figs. 7, 8, 9) that each columnar cell is narrowed by constrictions at intervals, so as to divide it imperfectly into a series of segments vertically superposed one upon another. The number of these segments varies according to the thickness of the disk; so that it is anything but constant, either in different individuals, or in different parts of the same. Moreover, it may be often observed that the columns neither always pass from end to end in a straight line, nor maintain a complete isolation from each other (Plate VIII. figs. 1, 2); an inosculation of two columns not being unfrequent, and more rarely a fusion of two columns into one. All these features of structure presented by the shell, are beautifully displayed by the animal (Plate IV. fig. 4); the columns of sarcode (*cc*, *c′c′*) exhibiting the imperfect transverse segmental division, the not unfrequent inosculation, and the occasional fusion, which we have seen to exist in the cavities which they occupy. At their upper and lower extremities, they unite with the horizontal bands (*bb′*, *bb′*), which pass continuously round, in each zone, between the intermediate and the superficial layers.

30. Save in the case of such accidental inosculations as those just noticed (which are indicated in vertical sections like that represented in Plate VI. fig. 7, by the irregularly disposed apertures *h*, *h*), no other lateral communication seems to exist between the contiguous cells of the same zone, than that which is established by the annular stolons just mentioned. The cells of the successive zones communicate with each other, however, as in the simple type previously described (¶ 17.); but with a curious modification; for whereas a horizontal section of the latter shows that each cell communicates with the *two* cells alternating with it in the interior zone (Plate V. fig. 1), a like section of the Orbitolite of complex type seems to show that such a connexion exists with only *one* cell of the interior zone, by a passage running obliquely from one to the other, and extending continuously through several successive zones (Plate V. fig. 6, *i*, *k*). I was long perplexed by the want of constancy in the direction of these passages; the very same section exhibiting opposite obliquities in contiguous parts (Plate VI. fig. 2). By the study of vertical sections, however, made tangentially instead of radially, so as to *cross* these connecting passages, I arrived at the explanation of this

apparent anomaly, which is simply as follows. Each columnar cell really communicates with the *two* alternating columnar cells in the next interior zone; but by two distinct passages, instead of by the divarication of one; and these passages are not upon the same plane, but those of different planes turn alternately to one side and to the other. This is well seen in the two tangential sections represented in Plate VI. figs. 8 & 9; of which 8 shows the back or central side of four contiguous columnar cells *aa'*, *bb'*, *cc'*, *dd'*, of the same zone, each of them perforated by a series of apertures, in which some degree of alternation is perceptible; whilst 9 shows the front or peripheral side of four other columnar cells, in which it is seen that, by the sinuosity of the partition, the apertures of any vertical row, even when in a line with each other, open alternately into the cells on the *right* and on the *left* of the septum; so that (*e.g.*) the passages extending backwards from the row of apertures in the columnar cell *bb'*, fig. 8, will debouch alternately in cells *aa'* and *bb'*, fig. 9, of the zone within. The same will of course be true of the pores which open on the margin, these being nothing else than the orifices of the inter-zonular passages just described, which, when another annulus is added, lead into its cells. This idea of the alternating direction of the inter-zonular passages, seemed to furnish the solution of the appearances presented in Plate VI. fig. 2; for, as the disks are seldom perfectly flat, the section which traverses, at one part of the disk, the set of passages running in one direction, will traverse the other set of passages, where, by the flexure of the disk, the plane of section is slightly altered in regard to it. All doubt, however, as to the validity of this explanation, was removed by the examination of the animal substance filling the vertical columns; for, as is shown in Plate IV. fig. 4, each column of sarcode in one zone (*cc*) does communicate with the two columns alternating with it in the next zone (*c'c'*) by two rows of peduncular stolons; and the peduncles which pass from each pair of contiguous columns, to the single column of the next zone, incline towards one another, so as to enter it nearly in the same vertical line, though in different horizontal planes.

31. That which has been already stated in regard to the partial deficiency of the inner wall in each of the concentric zones of the simple type (¶ 21.), holds good also in regard to the septa which divide the successive zones of the intermediate stratum in this more complex type; for the walls of the columnar cells close-in around them very imperfectly on their inner or central side, leaving large irregular vertical fissures (Plate VIII. fig. 1) which are applied to the vertical rows of orifices (Plate VIII. fig. 2) on the outer margin of the included zone.

32. The thickness of this intermediate stratum, and the number of vertical segments of which it consists, are found to vary considerably in different parts of the same disk; being usually least near the nucleus, and gradually augmenting in successive zones as their distance from the centre increases (Plate VI. fig. 7); or ceasing to augment at a certain point, so that the outer part of the disk is flat; or even diminishing again, so that the disk thins away towards its margin. It is specially worthy

of note, that whatever differences of this kind may exist, they are entirely due to the variable length of the columns of the *intermediate* stratum; the depth of the cells of the superficial layers being nearly constant, and no vertical multiplication of these ever taking place. The intermediate stratum, where it abuts on the nucleus, is often very thin; the annular stolons that run beneath the superficial layers being in such near proximity to each other, that the intervening column of sarcode is very short, and consists of only a single vertical segment, Plate V. fig. 12.

33. The foregoing description applies in every particular to those specimens only, which present the structure of this type of Orbitolite in its most regular and characteristic development; and the differences between this more complex form, and the simple form previously described, are such as at first sight to preclude the idea of their specific identity. Hence I am not in the least degree surprised, that Professor WILLIAMSON, by whom their respective plans of organization were first compared (*loc. cit.*), should have unhesitatingly regarded these two forms as specifically distinct. But when a large number of specimens of the more complex type are carefully examined and compared with each other, it becomes obvious that a vast amount of diversity in the arrangement of the cells of the shell, and of the segments of the animal, may present itself; and that one after another of the characters which at first seem most clearly marked and therefore most distinctive, may be shaded off (so to speak) in such a manner that a *complete transition is established,* sometimes even in a single disk, between the simple and complex types. Such a transition is exhibited by the specimen of which a vertical section is figured in Plate V. fig. 7; for it is obvious that the central portion of this disk (*a*—*b*) is so exactly conformable to the simpler type, that if this growth had stopped at the twenty-third zone, it would have undoubtedly been regarded as an unusually large example of that form. So many variations present themselves in the development of the different parts of the more complex type, that it will be desirable to describe them under a distinct head (Sect. IV.); and when these shall have been duly considered, I think that all doubt as to the specific identity of the simpler and more complex forms will be done away.

III. *Physiology.*

34. *Growth.*—Of the mode in which the *Nutritive* process is carried on in Orbitolites, our imperfect acquaintance with their living habits leaves us much in the dark; nevertheless it is fair to reason by analogy from a comparison of their structure with that of other Foraminifera whose habits of life are known; especially as this analogy is sufficiently complete in the present instance, to justify a tolerably firm reliance upon it, and as the results to which it would lead are in harmony with the facts of observation. All the Orbitolites, whether of the simple or complex type, which have been collected in the living state, have been found growing on the surface of Seaweeds or other marine plants (as *Zostera*), or of Zoophytes; it may therefore be fairly presumed, that such is their ordinary habitat; and hence it is scarcely conceivable

that their *attached* surface should ever be invested by sarcode. Moreover, several of the spirit-specimens which I have submitted to decalcification, have proved to be so closely invested by a covering of *vegetation*, chiefly composed of *Diatomaceæ*, *Desmidieæ*, and other minute Algæ, that I cannot suppose even the free surface of their disk to be ordinarily covered by sarcode*. The analogy of other Rhizopods, however, would lead us to suppose that the sarcode projects from the marginal pores under the form of *pseudopodia*, and that it is by the introduction of alimentary particles (chiefly minute forms of vegetation) through their means into the mass of sarcode from which they are put forth, that the fleshy body pervading the entire disk is nourished. For although there is nothing like a digestive cavity in any part of it, or an alimentary tube passing from one portion to another, still less any vascular communication between the segments, yet as the sarcode forms one soft homogeneous mass continuous throughout, the body as a whole will receive the benefit of any incorporation of new matter with its substance, in whatever situation this may be made. That organic particles small enough to pass through the marginal pores, are thus introduced into the chambers of the disk, is proved by the curious fact, that the residuum left after the decalcification of large and therefore aged disks, whose animal contents have not been preserved, consists almost entirely of an assemblage of remains of minute *Diatomaceæ*, *Desmidieæ*, &c., which have obviously been retained in the interior of their cavities, after the assimilation of the nutriment they were competent to afford.

35. The sarcode-body of the animal, growing at the expense of the nutriment thus appropriated, will gradually, it is probable, project itself through the marginal orifices, not merely in filamentous pseudopodia, but in quantity sufficient to form new segments on the outside of each pore; and these segments, extending themselves laterally, will come into mutual connexion, and will thus form a complete annulus. It may be presumed to be by the calcification of the surface of this beaded ring of sarcode, that the formation of the shelly zone is accomplished; and if the calcifying process commence on the segments, and extend from these along the surface of their connecting stolons, we can understand why the passages that are left for communication with the exterior, should arise from the intermediate divisions of the annular canal, instead of from the segments themselves.

36. The addition of new zones usually takes place with the same regularity in the complex as in the simple type of structure; but departures from this regularity, occasioned by a want of completeness of particular zones, are more frequent; and this is perhaps to be accounted for by the larger size of the disk, which will tend to produce a less intimate dependence of each part of the animal body upon every

* I have found such an investment also on several dried specimens; and until I had detached and examined this, I should have supposed from its aspect that it was the desiccated flesh of the animal. I have little doubt that the "greenish cuticle" described by Mr. Carter as covering his *Operculina arabica* (Ann. of Nat. Hist. ser. 2. vol. x. pp. 168, 172) and supposed by MM. d'Archiac and Haime (*op. cit.* p. 52) to be specially concerned in the formation of the shell, is of the same nature.

other, and will thus favour the partial action of any cause (*e. g.* an excess of nutrient materials) which promotes a more rapid growth on one side than on the other. And this view is most remarkably borne out by the fact, which I shall more fully illustrate in a subsequent memoir, that in another example of this group*, which, though normally growing upon the cyclical type, possesses a greater degree of segmental independence, such irregularities occur far more frequently; so that, in fact, it is rare to meet with a disk whose increase has taken place with uniformity throughout.

37. *Reparation of Injuries.*—Looking at that vegetative repetition of parts which pre-eminently characterizes the body of the Orbitolite,—every one of the segments first budded-off from the nucleus, and subsequently from the margin of the pre-formed zones, being the precise repetition of every other,—it may be expected from the analogy of similar organisms, that every one of these parts should be equally capable, both of repairing injuries done to itself, and of maintaining an independent existence when detached from the mass to which it originally belonged. And although no opportunity has yet presented itself, of subjecting such a conclusion to the test of experiments devised for the purpose, yet *accident* has furnished the means of verifying it, to a degree that could scarcely have been anticipated. For in the course of my examination of the large collections which have been placed at my disposal, I have met with several specimens, in which it is evident that, after larger or smaller portions of the disk had been broken away, a new growth has taken place along the fractured edge. Various examples of this are shown in Plate VIII. In the first that I happened to meet with, which is represented in fig. 6, the injury is evidently very slight, being confined to the loss of a few rows near the edge of the disk, for something less than half its circumference (*a*—*b*). This injury had obviously been sustained previously to the formation of the last two zones; for these, whilst added to the uninjured part of the margin in the usual way, have followed the irregular contour of the broken edge; and whilst in the former case the cells present their normal conformity to those of the margin they invest, in the latter, the cells, while obviously continuous with the preceding, are quite unconformable to those of the fractured margin, as is shown on a larger scale in fig. 7. Hence it seems to me probable, that the growth of these two rows along the *fractured* edge, has taken place, not from that edge itself, but by an extension of the sarcode about to form the new circle of the *entire* edge, from the points *a* and *b*. In fig. 9 is seen an example of a similar kind, in which a much larger portion of the disk has been broken away, so as to leave only an irregular fragment, including its centre and about an eighth of its margin. Here seven rows of cells have been formed since the injury; and these, whilst produced conformably to those of the uninjured margin, present the most marked want of conformity to those of the fractured margin, which, nevertheless, they completely surround. A careful examination of this specimen, indeed, seems to me to leave little room for doubt, that the growth of the innermost, or what I may call the *reparative* zone of

* I refer to a genus hitherto undescribed, which I shall designate *Cycloclypeus*.

cells, took place, not from the broken edge, but from the margin of the unbroken; just as, to use a professional simile, an ulcerated surface 'skins-over' by an extension of the integument from its edges, not by the direct formation of skin upon the granulation-surface itself. All the six rows subsequently produced, are conformable to each other, and to the first or reparative row, from which they have obviously extended themselves after the normal manner. It is observable, however, that the breadth of these rows varies in different parts, being least where they invest the projecting portions of the fractured edge, and greatest where they sink into its hollows. And thus it comes to pass, that the irregularities left in the shape of the disk, by the loss of a large part of its substance, are gradually compensated, so as to restore it to a form much more nearly corresponding to its typical symmetry.

38. Even a very small fragment appears thus to serve as the nucleus for a new disk. In fig. 8 is shown an example of this kind, in which the tendency to the reproduction of the typical form, by the compensative reparation just described, is very curiously marked. This specimen also presents the following very curious feature,—that the new growth has taken place from the *inner* margin of the original fragment (*aa*), and not from its *outer* or growing margin, as in the cases previously noticed. Having carefully examined it in various modes, I cannot entertain the slightest doubt that such has been the case; for the cells of the first new zone, as well as those of all the zones subsequently produced, are so manifestly conformable to those of the thinner and older portion of the fragment, and are so unconformable to those of the thicker and newer margin, that it seems obvious that the sarcode must have extended itself from the former part, along the fractured edge on each side, and have then enveloped the margin which had been left entire. This may have more readily taken place in the present instance, because at the part (*aa*) the fracture seems to have followed the course of one of the zones, instead of passing, as at the sides of this fragment, and in the instances previously cited, in such a direction as to cut the zones transversely.

39. The preceding instance clearly proves, that connexion with the central nucleus is not in the least degree requisite for the continued growth of the peripheral parts; since these may be entirely detached from it, without any loss of vital activity. The same inference may be deduced from the examination of specimens, in which, the central portion of the disk having been broken-out, a growth of new zones seems to have taken place from without inwards, so as to fill up the void space thus left. In no other way can I account for the appearances presented by a specimen in my possession, in which the included portion is as evidently unconformable to that which surrounds it, as it is in the preceding case, but in which there is also an unfilled void, the shape of one part of which clearly indicates that it occupies the site of the original centre. The *included* portion, and not the peripheral, must therefore be the after-growth in this instance; and if a little more time had elapsed, the whole of the central vacuity would probably have been filled up by it.

40. In the specimen represented in fig. 5, the central portion appears to have been lost, with about a third of the peripheral; and the new growth seems to have taken place at the same time, from the inner margin *a a a* of the fragment, and from its *outer* margin *b b b*, the two growths becoming continuous with each other along the broken edges *ab*, *ab*. For although the zones that lie internally to *a a a* are conformable to those which surround them, yet there is a peculiar character about them (more apparent in the specimen than in the drawing) which indicates them to have been formed at a later period, and to have been contemporaneous with those which surround the zone *b b b*. Their actual continuity at the angles *a a* is unfortunately interrupted by an injury which the specimen seems subsequently to have received; yet its traces are sufficiently perceptible on one side, to justify the belief in its former existence.—The specimen of which fig. 4 is a delineation, seems to have been the subject of several minor fractures and reparations; but the course of its zones marks out an obvious separation between an earlier- and a later-formed portion, one having sprung from the other along the line *a b*. The incompleteness of the specimen, however, prevents me from coming to any certain conclusion, whether the small inner portion is here the older, the large outer portion having grown in the first instance from its margin *a b*, and having gradually extended itself around it; or whether the outer portion is the residue of an unusually excentric disk, which, having lost its nucleus and the zones immediately surrounding it, has filled up the central space with an extension from its innermost zone, which is consequently the newest portion of the whole.—It is interesting to find evidence in *fossil* specimens, that the same kind of reparation has taken place. Among the Orbitolites which I have examined from the Calcaire grossier of Paris, is a disk of which a large part had obviously been lost by fracture, but of which the original symmetry had been in great degree restored by a similar outgrowth from the zones formed from the uninjured margin, along the fractured edge.

41. This series of abnormal phenomena, then, not only confirms the conclusion that seemed fairly deducible from our previous examination of the normal mode of growth, with regard to the independent endowments of the component segments of the Orbitolite body, but also affords some additional information of much interest. For we see, in the first place, that the growth of the sarcode, and the addition of new parts, may take place in the direction of the centre, where a free edge is exposed at the *inner* margin of any zone, as well as in the peripheral direction from the normal *outer* margin. Secondly, the reparative *nisus* seems always to tend towards the production of a disk, whose shape shall approach the circular, whatever may be the form of the fragment which serves as its foundation; thus showing that, notwithstanding the repetition and independence of the separate parts of these organisms, each cluster, whether large or small, is an integer, having an archetypal symmetry to which it tends to conform,—thus strongly reminding us of the laws of crystallization. And thirdly, the plan by which this recurrence to the discoidal form is provided for,

seems partly to consist in the limitation of the new growth to the natural margins of the zones; no such growth taking place from the edge of a fracture which has crossed the zones transversely, although it may proceed from the remains of a zone which has been broken off by a fracture that partly follows its course.

42. *Question of Individuality.*—It has been frequently discussed, whether each of the composite forms of Foraminifera, such as Orbitolite or Nummulite, is to be regarded as a *single individual,* or as a *colony* or *cluster of individuals.* All occasion for this discussion would, I think, be removed by the adoption of philosophical views as to what really constitutes an individual, and as to the relationship between the parts which, having a common origin in one generative act, are multiplied by a process of gemmation. As I have elsewhere endeavoured to show*, the entire product of every generative act, whether developing itself into a body of high organization, distinguished by the structural differentiation of its parts, or evolving itself as an almost homogeneous aggregate of equal and similar segments, must be regarded as homologically the same; and the essential difference between the two, as living beings, lies in the *functional* relations of their respective parts. For whilst in the former there is so close an *interdependence* amongst them all, that no one can exist without the rest, and the life of the whole is (as it were) the *product* of the lives of the component parts, there may be in the latter such a mutual *independence,* that each part can continue to live, grow, and reproduce itself when separated from the rest, so that the life of the whole is (so to speak) but the *sum* of that of its components. Now the term 'individual,' being commonly applied to the entire organism in the first case, and to only a small segment of it, perhaps, in the second, is obviously inappropriate either to one or to the other, except in so far as it expresses the fact of independent existence. But the limits of such individuality as this cannot be strictly defined, and they even differ widely in animals whose general plan of structure is the same†. Hence in regard to the Foraminifera, as in regard to Zoophytes, Composite Acalephæ, &c., we are to regard the entire mass originating in a generative act, as a *single organism*; and the question in regard to the *functional independence* of its multiple segments, is one of degree in each particular type. Thus, as we have seen, this independence exists in the case of the *Orbitolite* to such a degree as to make each part entirely self-sustaining, and to prevent the existence of any definite limit to the growth of the whole; yet it is quite possible that in a form so much more elevated as *Nummulite,* there may be, as maintained by MM. d'Archiac and Haime (*op. cit.* p. 69), such a degree of mutual dependence among the segments, and of unity in their aggregate life, that the latter predominates sufficiently to limit the growth of the organism to a tolerably determinate size‡.

* Principles of Comparative Physiology, chap. xi. sect. 1.

† See also Mr. Huxley's observations on this subject, in Philosophical Transactions, 1851, pp. 578, 580.

‡ Whilst admitting the possibility of this view, I shall hereafter have occasion to question its correctness; since the evidence on which it is based appears to me by no means satisfactory. In fact, when I come to

43. *Reproduction.*—The mode of *Reproduction* of the Foraminifera generally, is at present involved in the deepest obscurity; and there is little probability that it will be fully elucidated by any other means, than continued observation of the animals in their living state, such as may probably be best carried out with regard to the species of our own seas by keeping them in Vivaria. In default of such observations, and as a guide to further inquiry, I think it as well to state what has fallen under my own notice. In many parts of the body of spirit-specimens of *Orbitolite,*—especially, but not solely, in the superficial cells,—I have found the sarcode broken-up as it were into little spherules, as represented in Plate IV. fig. 3; these spherules, however, do not seem to possess any peculiar investment, nor does their sarcode appear to have undergone any special change. Similar spherules are figured by Professor EHRENBERG (*op. cit.*) in several of the cells of his *Sorites orbiculus*; and Professor SCHULTZE has recently (*op. cit.* pp. 26, 27) described bodies which seem to be of the same kind, though more opake (probably through having a denser envelope), as frequently presenting themselves in certain chambers of *Rotaliæ*, or even throughout the entire series. I feel much inclined to believe that these bodies are *gemmules*, which, like the zoospores of the Algæ, are produced by a resolution of certain portions of the substance of the organism into independent particles, which, spontaneously detaching themselves, and escaping through the marginal pores of the disk, will go forth to lay the foundation for new disks elsewhere.

Besides these, however, I have more rarely met with certain other bodies, apparently imbedded in the sarcode, which may be either gemmules in a later stage, or may possibly be true *ova*; these, represented in Plate IV. fig. 11, seem to exhibit various stages of binary subdivision; and they present a deep-red colour, even in spirit-specimens. I can scarcely imagine that these can be vegetable organisms that have been introduced through the marginal pores; since they are much too large to pass through these, without a great alteration in form; and this would seem to be incompatible with the firmness of their envelope. At *g*, fig. 11, is represented, under the same magnifying power with the foregoing, an object which I have detected in one of my vertical sections of the shell, where it occupies one of the superficial cells, the cover of which is deficient. Now it is quite possible that this cell may have been accidentally abraded, and that the object in question may have found its way into it *ab externo*; its position and aspect, however, seem to me much more conformable to the idea, that it has been developed in the disk itself, and that it has burst through the lid of the cell by its own enlargement, in preparation for its final escape. And this view seems borne out by the fact, that I have frequently found a few cells open on different parts of the surface of disks which did not appear to have suffered any abrasion; as if the rupture of their lids had taken place as an ordinary

describe (in a future memoir) the structure and varieties of *Nonionina*, the nearest existing type to Nummulite, and in my belief generically identical with it, I shall have occasion to show, that there is not only no proof of the existence of such a limitation to its growth, but that there is strong evidence to the contrary.

phenomenon of their development, instead of being the result of accident.—I do not wish to attach any weight to the interpretations I have here offered; but I simply state the facts, and the explanations of them which have suggested themselves to my own mind; merely adding, what I hope to present in more detail at a future opportunity, that bodies resembling the first or primordial cell, in which Foraminifera of all forms originate, are not unfrequently met-with in the chambers of many other species.

IV. *Variations.*

44. *Variations in Size.*—We have already seen that diversities both in the *diameter* and in the *thickness* of the disk, arise directly from the degree in which the animal substance (whereon the skeleton is modelled) has extended itself either *horizontally* or *vertically*, so as to multiply either the number of concentric rings, or the number of the superposed segments of which each ring consists. This, however, is not the only source of variation in size; for a most extraordinary diversity presents itself in the dimensions of the individual components, by whose repetition the entire disk is made up. It is in the *nucleus* that I find this diversity most strongly marked, as will appear from a comparison of Plate VII. figs. 1—4, which exhibit parts of a gradational series of twelve, from the smallest to the largest forms I have met with, all of them accurately drawn, under the same magnifying power, from specimens in my possession*. The length of the entire nucleus of fig. 4 is about *seven* times that of the nucleus of fig. 1, and its breadth about *four* times as great; the area of the former is therefore about twenty-eight times that of the latter; and as it is also several times as thick, the whole of the cavity, which was occupied in the living state by animal substance, could scarcely have been less than a *hundred times as large* in the one as in the other. (Compare also figs. 5, 6, 10, 12, 13 of Plate IV.) There is not by any means the same amount of difference between the dimensions of the ordinary cells which are formed by concentric extensions of the nucleus; nevertheless, it will be seen by a glance at the figures just referred-to, that these also exhibit marked diversities in size, the largest cells being usually found to spring from the largest nuclei, and *vice versâ*. Moreover, the individual cells of the very same disk are occasionally found to differ amongst each other, as widely as do the cells of fig. 1 from those of fig. 4.

45. Similar differences present themselves in the *thickness* of individual cells; as is of course best seen in the simple type of Orbitolite, in which the augmentation of thickness is not produced by the vertical superposition of multiple segments. A remarkable example of this kind is presented in the comparison of figs. 4 and 5 of Plate V.; these being, like the figures in Plate VII., drawn under the same magnifying power. I possess a series of vertical sections of different individuals, in which the same gradual transition is seen from the thin to the thick, as I have just stated

* The entire series of figures is in the possession of the Royal Society.

to exist in regard to superficial area; and which also proves that the relative thickness of the central and of the peripheral portions is equally liable to variation.

46. It seems obvious, from the foregoing considerations, that neither the absolute nor the relative dimensions of the individual parts of these composite fabrics, can, any more than the dimensions of the entire disks, be taken as affording valid characters for the discrimination of species; and that such a wide range of variation exists among individuals, as would, if the extreme cases alone were known, seem fully to justify their separation under distinct specific designations. Thus, if the two extreme forms, figs. 1 and 4 (Plate VII.), had been the sole objects of comparison, most naturalists would undoubtedly have considered the strongly-marked difference in the size of their respective nuclei to entitle them to rank as separate species; and even if fig. 2 or fig. 3 had been brought into comparison with them, it might have been a question whether it should be associated with fig. 1 or with fig. 4, or should rank as a third species intermediate between them, or should be considered as a connecting link specifically identical with both, and therefore establishing their specific identity with each other. The comparison of the entire series must be felt to remove all ground for hesitation on this point, since it is manifestly impossible to draw a line across any part of it, which should divide it into two or any larger number of groups, respectively characterized by constant and well-marked differences in size. And here again, therefore, we have evidence of the great importance of bringing into comparison a sufficiently large number of forms, to enable us to determine in some degree the measure of individual variation.

47. *Variations in Shape.*—The very strong tendency which we have seen to prevail in the Orbitolite, not only to the maintenance of the circular type in the regular growth of the disk, but to its reproduction after accidental injuries, seems to prevent the occurrence of any considerable variation in its general form, except such as may be directly produced by external agencies. The circular sometimes gives place to an elliptical shape (Plate VII. fig. 4), especially in young specimens, whose form is more determined by that of the nucleus than is that of older individuals. And the occurrence of such a variety in the recent type, makes me indisposed to admit that ellipticity of shape can be in itself a sufficient basis for the specific differentiation of any fossil form of this genus. Of the marked differences in the general aspect of the disks, which may arise from differences in the relative proportions between their thickness and their diameter, and in the relative thickness of their central and peripheral portions, mention has been already made (¶¶ 17 and 32.). And the only other important departure from the typical shape which I have met with, either in the simple or in the more complex form, has been described under a former head (¶ 25.).

48. *Variations in the Form of the Superficial Cells, and in the Markings of the Surface.*—The appearances presented on minute observation by the surface of the Orbitolite, are so far from being uniform, that to any one whose eye had not become

familiarised with their variety by the examination of a considerable number of specimens, they would become sources of great perplexity. We have already seen that the cellular markings present two very distinct forms, the *rounded* (Plate V. fig. 1) and the *oblong* (Plate V. fig. 6); the first of these being specially characteristic of that simpler type of structure in which there is only a single layer of cells, but not being confined to it; whilst the second is peculiar to the complex type, in which there are two superficial layers, distinct from the intermediate stratum. Now the occasional coexistence of both these plans of structure in a single individual (¶ 33.), sufficiently proves that the diversity of the surface-markings to which they respectively give rise, cannot be regarded as a basis for specific distinction; and when these extremes of diversity are kept in view, it must be felt to be highly improbable that any modifications of either form should possess greater importance. That such modifications are mere individual varieties, is further evidenced by their *gradational* character, and by the fact that two or more of them may present themselves in the same disk. In my description of them, I shall limit myself to an account of those more remarkable and frequently-recurring varieties, which will serve, I think, as a key to any others that are likely to be met with.

49. Although each surface, in either of the two principal types, ordinarily shows a division into concentric zones, which are again transversely subdivided so as to mark the separation of the cells, yet sometimes the concentric zones are alone visible, and no transverse subdivision is indicated, save by the alternation of lights and shadows proceeding from a like alternation of solid substance and of hollow spaces beneath (Plate VII. fig. 7). This predominance of the concentric divisions, which gives a very distinctive aspect to the disks which exhibit it, is usually most apparent in individuals whose vertical section exhibits two planes of cells; and it has seemed to me to depend on the unusual freedom between the *lateral* communications, which I have noticed in certain individuals thus formed, so that the animal portion of each zone might be described as an annulus of sarcode, merely constricted at intervals. This peculiarly cyclical aspect of the surface (on whose occurrence in fossil specimens I believe the genus *Cyclolina* to have been founded, ¶ 5.) may pass into either of the principal types previously noticed; thus in fig. 14 we observe the concentric zones, though still very strongly marked, breaking up (so to speak) into bands of rounded cells with slightly convex covers; whilst in figs. 5, 6 they are subdivided by very definite transverse lines into cells of remarkable squareness, which still retain the original flatness of their surfaces.

50. On the other hand, the appearance of concentric division is sometimes almost entirely wanting; the surface of the disk exhibiting excentric circular markings, which resemble those of an engine-turned watch-case (Plate VII. fig. 8), and the boundaries of the cells being formed by the intersection of these with each other. This aspect, however, which seems due to an unusual freedom in the *oblique* communications between the cells in each zone and those alternating with them in the

contiguous zones on either side, insensibly passes into the ordinary type; and it is not uncommon to meet with disks, especially fossil, which exhibit in one part the engine-turned aspect (Plate VII. fig. 8), and in another (fig. 14) that of concentric zones transversely subdivided. Indeed I have sometimes found that the very same disk might be made to present either of these aspects, according to the manner in which the light is made to impinge upon it and is reflected from it.

51. Although the rounded or ovoidal form of the superficial divisions is specially characteristic of the simple type of Orbitolites, yet it is by no means restricted to this; being frequently met-with in the thicker disks of the more complex type, and being almost constant in the fossil forms that abound in the early Tertiaries. Its occurrence, however, may always (I believe) be considered as indicating an incomplete separation between the superficial cells and the columnar cells of the intermediate stratum (¶ 58.); so that the former present the shape of the latter, in place of the form which properly characterises them. The shape of the cell is sometimes marked out in unusual strength by the convexity of its lid or cover, as shown in Plate VII. fig. 15; and this feature is often so pronounced in the large fossil Orbitolites of the Paris basin, as to become visible to the naked eye. A very marked diversity in its degree, however, as well as in the size of the cells, is to be noticed in the contiguous zones of another specimen (Plate VII. fig. 16); whence it is obvious that the convexity is a mere accidental variation, and is a character of no value whatever as regards the differentiation of species. The relation of the rounded to the square or oblong cells is made evident by the occurrence of intermediate links of transition. Thus, from such *circular* cells as are delineated in Plate VII. fig. 9, the passage is easy, through those shown in figs. 8 and 14, to those of fig. 6 (which are drawn under about twice the magnifying power), and thence to the *square* cells of the inner part of the portion of the disk figured in Plate VII. fig. 13. This last figure illustrates the important fact, that while the cells in one part of the surface of the disk are *square*, others in close proximity with them may be *oblong*; thus conducting us to the extreme form of this type, represented in Plate VII. fig. 12.

52. The foregoing considerations seem to render it obvious, that the diversities in the *form* of the superficial cells do not afford any ground whatever for the establishment of a corresponding multiplicity of specific types, but that they must rank as individual variations to which there is scarcely any definite limit. If the originals of Plate VII. figs. 5, 7, 9, 12 and 15, had happened to have presented themselves to the Systematist without any of the connecting forms, he might have been pardoned for describing them as distinct species characterised by well-marked differences in the form and arrangement of their cells; but no such differentiation can be admitted in the face of the fact, that these are only extreme examples of variations, which show themselves in a minor degree between almost every two specimens brought into comparison, and even between the different parts of the same disk. Moreover, when it is borne in mind, that the animal basis on which the calcareous skeleton is moulded

is not a body of constant shape, provided with organs having a fixed relation one to another, but is a mass of almost homogeneous sarcode, which in the living state is continually undergoing changes of form, one part extending itself into pseudopodia, whilst another undergoes a corresponding contraction, a strong *à priori* improbability is seen to exist, that, in animals of such organization, the form of the component segments should possess that value as a specific character, which it can only derive from *constancy*.

53. Besides those regular markings of the surface, which correspond to the division of the interior into cells, a peculiar aspect is frequently given to it by the deposit of calcareous thickenings, which are sometimes irregular, but which occasionally present an approach to symmetry. The most remarkable example I have met with, of this kind of addition, is delineated in Plate VII. fig. 11, in which it will be seen that the deposit has taken place in radial lines disposed with a certain degree of regularity. But in fig. 10, which represents a specimen whose surface is far less altered by these deposits, no such symmetry presents itself; and other specimens in my possession exhibit the means between these extremes. Hence we are justified in pronouncing this peculiarity to result from an accidental outgrowth, which is so variable in its degree as not to afford the least basis for specific differentiation. It is worthy of note, however, that it presents itself far more frequently, and also in a far more characteristic manner, in the Orbitolites of the Philippine Seas, than in those of the Australian or of any other provinces; and this circumstance seems to render it probable, that the outgrowth is directly due to the influence of some external conditions, probably to an excess in the proportion of carbonate of lime in the waters inhabited by these particular specimens.

54. *Variations in Mode of Growth.*—Although the cyclical mode of growth, when once established, is subsequently maintained with great regularity, and although in what may be considered the typical form, it commences from the 'nucleus' itself, yet there are numerous instances in which the typical regularity is more or less widely departed-from, so that the early increase seems to take place after an altogether different plan. The most marked antithesis to that regularly concentric type of growth, in which a complete annulus of cells is formed around the large circumambient segment of the 'nucleus' (see ¶ 17, also Plate IV. fig. 5, and Plate VII. fig. 2), is presented by those forms in which this circumambient mass only gives origin to new cells at its extremity; these in their turn bud-forth others, which extend and multiply themselves laterally as well as in advance; and thus a kind of spiral is produced, which opens-out very rapidly, the lateral portions of its mouth tending to grow-round and embrace the nucleus. Thus, starting from the central globular mass, 1, of Plate IX. fig. 4, we see that the circumambient mass 2 2, which nearly surrounds it, gives origin at one of its extremities to a smaller mass, 3, from which bud-off two cells, 4 4, which again give origin to four cells, constituting the row 5 5. The cells of the next row, 6 6, are more numerous, but are themselves exceeded by

those of the zone 7 7, which not only surrounds it, but extends further backwards upon the nucleus. So the cells of the zones 8 8, 9 9, 10 10, 11 11, and 12 12, progressively increase in number, and each zone extends itself further back upon the nucleus, until those of the last of these zones nearly meet upon its yet unenclosed margin. The cells of zone 13 13 do actually meet there, so as to form a complete circle; and zones 14 14 and 15 15 are formed with cyclical regularity, as would be any other zones subsequently produced. A still more complete spiral, in which twenty-two zones (commencing with the central segment) succeed one another before the first complete annulus is formed, is shown in Plate IX. fig. 2. Both figs. 2 and 4 (the latter of which is diagrammatized) represent the central portions of large disks, whose peripheral portions grow on the regular cyclical plan.

55. Now if these two plans of growth—the one cyclical from the beginning, the other cyclical only after having been at first spiral—were constantly presented in well-marked contrast with each other, there would be good ground for considering them (as Professor WILLIAMSON has done*) to be characteristic of distinct specific types. But this idea cannot be entertained, when a large number of individuals are examined. For it then becomes apparent, that the number of cases in which the nucleus is surrounded on all sides by the same number of zones, indicating that the concentric mode of growth has prevailed from the very first, are very few; but that in by far the larger proportion of specimens, there is a slight excentricity of the nucleus, with a larger number of zones on one side than on the other, as in Plate IX. figs. 1, 3; indicating that the first-formed zones have been incomplete circles, owing to a restriction of the gemmation of the nucleus to one part of its periphery. This is shown extremely well by decalcified specimens of the animal, no two of which, in fact, precisely resemble one another as to the mode in which the first zone of segments originates in the nucleus. Thus in the specimen represented in Plate IV. fig. 1, of which the nucleus is represented on a larger scale in fig. 12, the circumambient segment of the nucleus gives off only *three* stolons, at the end most remote from its connexion with the central mass; and the first zone of segments is far from being entire, the cyclical type not being completely attained until two or three successive additions have been made. In fig. 13, *eight* stolons are given off from the nucleus; and from the half-zone which they form, an entire circle is next produced; thus affording a remarkable confirmation to the idea I have already suggested (¶ 37.), as to the capacity of a portion of a zone to give origin to a complete annulus, by the lateral extension of its bands of sarcode. In fig. 10, the nucleus gives off *eleven* stolons on one side, and there are indications of *three* or *four* on the other. In fig. 6, the stolons come forth from a still larger proportion of the periphery of the nucleus; the zone which first surrounds it, however, is still incomplete in some parts, though the succeeding zone forms an entire circle. Finally, in the specimen represented in fig. 5, which is almost the exact counterpart of the disk represented in Plate VII. fig. 2,

* Transactions of the Microscopical Society, 1st series, vol. iii. pp. 116, 119.

the stolons pullulate from the entire circumference of the nucleus, and the annular zones of segments are complete from the first. The greater the limitation of the power of gemmation to one side of the nucleus, and the larger the number of incomplete zones, the more will the early plan of growth approximate to the spiral type, such as is represented in Plate IX. figs. 2, 4. It is obvious that the existence of these intermediate gradations breaks-down that barrier between the extreme forms, which Professor WILLIAMSON had proposed to erect; and shows that in this, as in many other particulars, differential characters, which at first sight appeared to be perfectly satisfactory, lose all their force when carefully traced through a sufficiently extended series of specimens.

56. It is desirable to note, as bearing on the relations between *Orbitolites* and *Orbiculina*, that even in those forms of the first-named type, in which the *spiral* mode of early growth is most characteristically displayed, it never seems to proceed far beyond a single turn; and further, that the later portion of this whorl merely surrounds the earlier, and does not cover it; so that unless (as sometimes happens, Plate V. fig. 5) the nucleus should itself be thicker than the zones of cells which immediately surround it, there is no central protuberance. In *Orbiculina*, on the other hand, the early growth invariably takes place according to the spiral type; this type is always maintained, until several turns have been made; and the later whorls not only surround but cover-in the earlier, so as to give rise to the central knob or protuberance. Some general remarks, which I have to make on the combination of the helical and cyclical types of growth, bearing upon certain fundamental questions of classification, will be more appropriately introduced in a subsequent Memoir, after the structure of *Orbiculina* shall have been compared with that of *Orbitolites*.

57. It is not, however, in the early mode of development alone, that striking diversities present themselves; for numerous variations, some of them quite as remarkable, are seen in the course of the evolution of the several parts which are characteristic of the 'complex' type. Thus, in the first place, the intermediate stratum is sometimes entirely deficient in the zones immediately surrounding the nucleus; so that the upper and lower annuli of sarcode are represented by only a single band, as is indicated by the singleness of the aperture through which it passes. In the specimen figured in Plate V. fig. 9, we see this to be the case only with the *three* zones nearest the centre; in that represented in Plate V. fig. 10, the canal is single in the *five* inner zones; whilst in that represented in Plate V. fig. 7, the canal is single for the first *twenty-three* zones. Whenever the annular canal is single, the upper and lower superficial cells also become continuous, and form a series of columnar cells in every respect similar to those of the simpler type (compare Plate V. fig. 5 with the portion *a—b* of Plate V. fig. 7). If, then, the growth of either of these disks had been checked within the first zone in which its annular canal becomes double, it would have been accounted as belonging to the simpler type; and the wide variation which here shows itself, in regard to the distance from the nucleus at which the more com-

plex type begins to be assumed, sufficiently explains the fact already noticed (¶ 22.), that although the disks of the 'simple' type are for the most part of minute size, yet that the diameter of many of them exceeds that of the smaller disks of the complex type.

58. Even when an intermediate stratum is formed by the separation of the annular canals, the superficial cells are not always clearly marked-off from its columnar cavities; for instead of being separated by floors formed by the expanded summits of the zonal septa (¶ 28.), they sometimes open at once into the columnar cells of the intermediate substance, so as to be quite continuous with them. Of this we have an example in the three zones 6—8 of the specimen represented in Plate V. fig. 10, *b*—*c*. This continuity of the superficial cells with the intermediate columns, is sometimes maintained throughout the disk, so that in no part of it are the former clearly marked off from the latter; as is seen in the portion *b*—*d* of fig. 7, Plate V.; in which, however, the intermediate layer is much less regular than usual. This method of growth is so remarkably constant in the *Fossil* Orbitolites of the Eocene strata, whose intermediate layer is fully and very regularly developed (see Plate VI. figs. 10, 11, and Plate VIII. fig. 2), that it might be considered to be specifically characteristic of them, did we not occasionally find it to occur in certain zones of recent disks, which are elsewhere exactly conformable to what I have described as the regular type. Thus in the vertical section represented in Plate V. fig. 10, we see that whilst the superficial cells of the three zones *b*—*c* are continuous with the columns of the intermediate stratum, a change then occurs in the relative places of their zonal septa, so that the cells of the former come to be, as it were, detached from the columns of the latter, and to have floors formed by the summits of the partitions by which these are divided. It is, as already remarked (¶ 51.), where the superficial cells are continuous with the columnar cells of the intermediate substance, that they present the rounded or ovoidal shape, instead of the elongated straight-sided figure which is their characteristic form. And the former seems to give place to the latter, whenever the cells of the superficial layers are perfectly separated from those of the intermediate stratum, and are connected only with the annular passages.

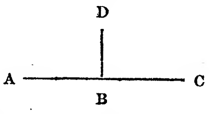
59. The intermediate stratum, again, may be altogether wanting, notwithstanding that the two superficial layers are separated from each other by a horizontal partition. In this case, each layer has its own annular canal; and its cells have sometimes such an arrangement as regards those of the other layer, that one of the connecting stolons from which each segment arises, will pass into the alternating cell of the upper layer, and the other into that of the lower. This arrangement may present itself as one of the modes of transition from the simpler to the more complex type, as is shown in Plate V. fig. 9; the columns being disposed to subdivide transversely when they attain a considerable length, and the annular canal becoming double; whilst in zones more distant from the centre, the two layers are separated by the interposition of the intermediate stratum. Sometimes, however, the disk continues to increase and attains

a considerable size on this duplex type; and its edge then presents two rows of rounded prominences with pores between them, those of the upper and lower rows alternating with each other, as is well seen in the vertical plate of the monstrosity represented in Plate IX. fig. 10. It is on a disk of this type that Professor EHRENBERG has founded his genus *Amphisorus*, which I cannot regard as even specifically distinct from the ordinary Orbitolite.

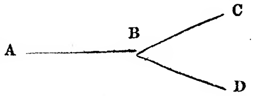
60. The next variety to be noticed, consists in a complete absence of regularity in the disposition of the columnar cells of the intermediate stratum, so that they present an assemblage of indefinitely-shaped passages, communicating with each other in various directions. This variety is chiefly interesting, as showing how little importance is to be attached to smaller deviations of the same kind. The most remarkable example of it which I have met-with, is represented in Plate V. fig. 7, *c—d*. In Plate V. figs. 11, 12 are represented two examples of irregularity in the disposition of the superficial and intermediate cells in the zones immediately surrounding the centre.

61. Lastly, I have to mention, that the septa dividing the contiguous cells of the same zone are occasionally deficient, so that the interior of the zone is a continuous circular passage, with only slight indications of the normal divisions. In such a case, it is obvious that the ring of sarcode must have been everywhere of nearly uniform thickness, showing no division either into horizontal or into vertical segments; and it may not be thought improbable that this is its first condition in every case, and that its segmental division is a subsequent process, so that the shelly investment, if formed previously to the segmentation, will have the character of incompleteness just described. I cannot help suspecting, that the peculiar groove around the margin of the Feejee specimens formerly noticed (¶ 25.), is referable to a still greater incompleteness of the production of the calcareous investment around the newly-forming zone.

62. *Monstrosities.*—Besides those departures from the normal type of growth, which have been described as variations or irregularities, there are certain others of rarer occurrence, which can only be regarded as '*monstrosities by excess*;' consisting in the production of one or more incomplete secondary disks by outgrowth from the first. In the specimen represented in Plate IX. fig. 8, the secondary disk forms a half-circle BD, of about the same diameter with the primary AC, and is superposed vertically upon the latter, the plane of junction passing through its centre. In the specimens represented in figs. 7 and 9, the secondary disk is relatively smaller, extending only from the centre to the margin of the primary, but still meeting it nearly at right angles.



—In the specimen of which two different aspects are shown in figs. 5, 6, it would seem difficult to say which is the primary and which the secondary disk, and it would be more correct to describe the entire structure as consisting of a single half-disk AB and of two half-disks BC and BD, meeting each other at an acute angle CBD, neither of them being in the same plane with the single half-disk, but both of them meeting it at similarly obtuse angles ABC and ABD. The opening of one of the



obtuse angles is shown in fig. 6, and that of the acute in fig. 5; and in each view it is seen, that the divergence takes place in a plane which passes through the common centre of all three.—The specimen delineated in fig. 10 exhibits a multiple outgrowth of a nature resembling that shown in figs. 8 and 9. For from the surface of the disk there rises a triradiate crest, formed by three vertical plates meeting one another at nearly equal angles, but all of them nearly perpendicular to the plane on which they rest. It is a very remarkable feature in this specimen, however, that the line in which the three vertical planes meet, is traceable at its base to the nucleus of the horizontal disk; so that they all bear the same relation to it, as does the single outgrowth in the instances previously cited. Hence we may attribute all these monstrosities to an excess of productive power in the sarcode of the original nucleus, which has put forth its first extension, not merely in the horizontal, but also in the perpendicular direction; the whole subsequent development of these outgrowths taking place after the normal plan, from the foundation thus laid.—It is interesting to remark, that the presence of such outgrowths as those now described, is far more frequent in certain localities than it is in others. Among some hundreds of specimens which I have examined from the coast of Australia, I have only met with those represented in figs. 7, 8, 9, and two or three others; the remarkable specimen delineated in figs. 5, 6, occurred with another less peculiar among a comparatively small number of Orbitolites collected by Mr. Cuming in the Philippine Seas; but in a small collection which I have inspected from the Ægean Sea, the monstrosities of this kind (of which fig. 10 was the most remarkable) were so numerous, that I think I am scarcely wrong in asserting that one specimen out of every three or four presented some excess*. Among the *fossil* Orbitolites of the Paris basin, the presence of a completely-semicircular vertical plate is not at all uncommon.

63. There may be some doubt in the first instance, as to the light in which we are to regard the specimen represented in Plate VIII. fig. 10; whether as a 'monstrosity by excess,' or as the product of the fusion of two individuals: but I think this will be removed by a closer examination. For it is obvious, that the smaller disk, which is surrounded by the outer zones of the larger one, has been developed from a nucleus of its own; and this nucleus does not appear to have any direct connexion with the periphery, still less with the centre, of the larger disk: on the other hand, when we consider the circumstances under which Orbitolites grow (¶ 34.), it is very easy to understand, that the smaller and younger individual, having attached itself in too near proximity to the larger and older one, should become imbedded therein (so to speak) by the extension of the newly-forming zones of the latter around its margin.

* This is by no means a solitary case of the prevalence of monstrosities in particular localities. The collection of Mr. Bean of Scarborough contains a number of curiously-distorted specimens of the common *Planorbis marginatus,* which have all been collected in one brook. Their peculiarities are by no means repetitions of each other; and I am disposed, therefore, to regard them rather as resulting from the influence of external conditions, than as accidental varieties hereditarily propagated.

In fact, the manner in which the outer zones of the larger disk envelope the smaller, precisely corresponds with that in which we have seen the new zones originating from the uninjured margin of a mutilated specimen, to extend themselves along its fractured edges (¶ 37.).

V. *Of the Essential Characters of Orbitolites, and of its relations to other Types of Structure.*

64. If, now, we seek to determine the essential characters of that type of organization which is known under the designation *Orbitolites*, we find them to lie in the presence of *a series of annuli of sarcode* (and of corresponding *passages* in the shelly disk) arranged concentrically round a nucleus; each zone in the simpler type containing but a *single* annulus, so constricted at intervals as to form a series of somewhat columnar segments (occupying the cells of the shelly disk), connected with each other by narrow bands of sarcode; whilst in the more complex type each zone contains two such annuli, including between them a portion of its series of columnar segments, so as to constitute an *intermediate* stratum, distinct from the *superficial* portions. In either case, the segments of successive zones freely communicate with each other by *radiating bands of sarcode* (also leaving *passages* in the shelly disk), whose normal direction is such as to connect each segment with the two segments that alternate with it in each of the adjacent zones.

65. Now the addition of new zones, each similar to the last, is a simple matter of *growth*; but the passage from the simpler to the more complex plan marks an advance in *development*; and this advance essentially consists (here as elsewhere) in a progressive *differentiation of parts.* When, with the vertical extension of the columnar segments, the annular canal subdivides itself into two, the communications between the successive zones no longer come-off, as before, from the annular canal, but from the intermediate portions of the columnar cells; and instead of the two diverging passages from each cell being in the same plane, they lie in different planes, alternating with each other vertically. Up to this point, we observe little else than a multiplication of parts vertically, as well as horizontally, and a separation of connexions that were previously confluent. But in the highest stage of development, we find a marked alteration in plan; for those portions of the columnar segments, which lie between the two annular canals of each zone and the two surfaces of the disk, become completely differentiated from the portions that occupy the intermediate stratum, so as to form a peculiar set of *superficial cells*; and these are so equally connected with *two* zones, as to make it impossible to say that they belong specially to either.

66. Now we have seen that *development* may be checked, while *growth* continues, at any period of its progress; so that we find Orbitolites growing to a considerable size upon the very simplest plan,—others still larger formed upon the duplex plan,—the largest yet known (fossilized in the Paris basin) developed upon the multiple plan

without separation of the superficial cells,—while the most complete, in regard alike to multiplication and to differentiation of parts, are only found among the disks at present existing; and it is interesting to observe, that some of them present this highest grade of development, while as yet of comparatively minute size. I am not acquainted with any other Animal body, in which so wide a range of developmental variation normally exists. The lower classes of the Vegetable Kingdom, however, especially the group of Fungi, afford abundant examples of it *.

67. The extreme freedom with which all the cavities of the shell mutually communicate, is a very marked feature in the structure of this type; and shows that the several parts of the animal body are far more closely connected into one whole, than they are in most of the other Foraminifera whose general plan of conformation is more or less analogous. Indeed, if we were to imagine a discoidal mass of sarcode to be traversed by a reticulated calcareous skeleton, somewhat resembling that open areolar texture which forms the *shell* of the Echinida, and this network to possess something of that regularity of the disposition of its successively formed parts, which is presented to us in the *spines* of the Echinida, we should have no unapt representation of the relation of the shelly disk of the Orbitolite to the animal which it envelopes. There are certain Sponges which have a reticulated skeleton composed of mineral matter disposed in a mode not altogether dissimilar, whilst the constitution of their soft bodies is essentially the same. And a remarkable connecting link between Orbitolites and Sponges, seems to be presented to us in the curious *Thalassicolla* discovered by Mr. HUXLEY †. The relations of Orbitolite to other Foraminifera have already been partly touched-on, and will become more clear hereafter, when the types which most approximate to it shall have been themselves described.

VI. *Of the Species of Orbitolites.*

68. It only remains to inquire, whether the diversities which have been described as existing among Orbitolites, afford any ground for assuming the existence of more than a single species. With regard to the *recent* forms, with which, so far as they are at present known, I have made myself fully acquainted, I can speak confidently; since, as I have demonstrated, the Orbitolite with a *single* stratum of cells (*O. marginalis* of LAMARCK, *Sorites* of EHRENBERG), that with a *double* stratum (*Amphisorus* of EHRENBERG), and that with *multiple* strata (*Marginopora* of QUOY and GAIMARD, *Orbiculina Tonga* of Professor WILLIAMSON), are fundamentally the same forms, developed in three different modes.

69. Of the identity of all the *fossil* species with the foregoing, I cannot speak with the same confidence; since there are some of which I can only judge from figures. Into the structure of that which is best known, however, and which has been commonly accounted the type of the genus, viz. the *Orbitolites complanata* of the Paris

* See especially the recent Memoirs of M. TULASNE, in the 'Annales des Sciences Naturelles.'

† Annals of Natural History, 2nd series, vol. viii. p. 433.

basin, I have made investigations scarcely less minute and extended than into that of the recent forms; and I have come to the conclusion, that it cannot be specially distinguished from the large Australian Orbitolite, to which it bears a very obvious general conformity. It is true that it differs from the typical forms of the latter in two important features of structure, which are, however, mutually connected;—namely, the direct continuity of the cells of the superficial layers with the columnar cells of the intermediate layers; and the rounded or ovoidal form of the superficial cells, which (as already stated) these always possess, as in the simpler type, unless they are disconnected with the columnar cells, and communicate only with the annular stolons (see ¶ 58.). But since this very peculiarity does present itself in certain existing individuals, whose development seems to have taken place upon a lower type, and since it occasionally shows itself in the course of the passage from the simplest to the most complex type, in such as ultimately attain the latter, there appears to me no room for questioning the specific identity of the *O. complanata* with the Australian forms, notwithstanding that I have never met, among the numerous specimens which I have examined of the former, with those elongated parallel-walled superficial cells, which constitute the most distinctive feature in the latter. It may be well, moreover, to bear in mind the remark I have already made, respecting the local prevalence of particular varieties of form; since there is nothing more strange in the incompleteness of the type of development presented by the Paris-basin Orbitolite, than in that tendency to excessive development, which gives rise to the numerous monstrosities that are presented by the Ægean specimens (¶ 62.), or in those radial deposits on the surface, which are so common among the Philippine forms (¶ 53.). My belief in the specific identity of this fossil with the recent types has been strongly confirmed by the circumstance, that among the Paris-basin forms I have found a minute specimen, which corresponds in every respect with the simple type of the existing species.

70. Of the other fossil species cited by Lamarck, the *O. macropora* of the Maestricht beds, judging from the figure given of it by Goldfuss, is nothing else than an Orbitolite of simple type, whose marginal cells have been laid open by attrition both above and below, as in Plate VII. figs. 8, 10. The *O. concava* and *O. pileolus* of Lamarck are not distinguished in his definition by any other character than that drawn from *form*, which we have seen to be so variable as to be quite insufficient as a distinctive feature. It is quite possible, moreover, that they may belong to another type, nothing being said in the description of them, either of concentric lines, or of pores. If, as I believe, the *O. concava* of Lamarck (figured by Michelin in his 'Icon. Zoophyt.,' pl. 7. fig. 9) be identical with the *O. conica* of M. d'Archiac, I feel certain (from careful examination of its imperfectly-preserved internal structure) that, whatever it may prove to be, it is *not* an Orbitolite. So again, the *O. lenticulata* of Lamarck, judging by the figure given of it by Lamouroux *, is *not* an Orbitolite,

* Polypiers, pl. 72. figs. 13, 16.

but probably a Lunulite. Of the species subsequently described by other authors, I entertain no doubt that the *O. disculus* of M. Leymerie *, as well as in all probability the *O. plana* of M. d'Archiac, is nothing else than a variety of *O. complanata*, more especially as its young is said to be like the *O. macropora* of Maestricht. The *O. gensacica*, *O. secans*, and *O. socialis* of M. Leymerie, are all undoubtedly *Orbitoides*, and all belong, I believe, to the same species; though on this point I could not speak positively, without an examination of their internal structure. So, again, the *O. mamillata*, *O. Fortisii* (*O. gigantea* of D'Orbigny), *O. papyracea*, *O. stellata*, *O. sella* and *O. radians* (*O. radiata* of D'Orbigny) of M. d'Archiac † are all probably Orbitoides, as he has himself subsequently recognized in regard at least to some of them ‡. The *O. elliptica* of Michelin, so far as I can judge from the figure he gives of it (pl. 71, fig. 11), is certainly not entitled to rank as a distinct species, its elliptic form being utterly insufficient to separate it (¶ 47.). And as I have already pointed out (¶ 49.), unless some distinctive character be furnished by the internal conformation of the bodies which have been ranked in the genus *Cyclolina* by M. d'Orbigny, this also should take rank merely as a variety of Orbitolites §.

VII. *Concluding Remarks.*

71. It might be asked with some show of reason, what good purpose can possibly be answered by such a minute and prolix description of a type of animal structure, so mean and insignificant as that which has been occupying our attention. To such a question I would reply—First, that I hold it to be a worthy labour to learn, and to place within reach of others, *everything* that *can* be learned respecting *any* form of Organized Being; that such a complete acquaintance is the great desideratum in every department of Biological Science; and that no works have ever exercised so beneficial an influence on its progress, as those admirable Monographs of single species, which, by thoroughly elucidating their structure and physiological history, have served as a basis for all subsequent inquiry into the nature of the Plants or Animals formed on a like plan:—Secondly, that such an inquiry can scarcely be otherwise than of peculiar utility, as relating to a tribe of Animals whose nature and history are almost as unknown to us now, as those of Polypes were to the Naturalists of a century ago, when Trembley wrote his immortal 'Mémoires pour servir à l'Histoire d'un Genre de Polypes d'eau douce;' what little *is* known respecting them, being of a nature to mark them as distinct from every other type of living beings

* Mém. Géol. Soc. de France, 2 sér., tom. v. pp. 190, 191.

† *Ibid.* tom. ii. p. 178, and 2 sér., tom. iii. p. 4.

‡ Description des Animaux Fossiles du groupe Nummulitique de l'Inde, p. 350.

§ For a recent description of a form of this reputed genus, which occurs in contiguity with typical Orbitolites, and which seems to me to correspond in every respect with those recent specimens of which Plate VII. fig. 14 exhibits the external aspect, see Mr. Carter's Memoir on the Fossil Foraminifera of Scinde, in 'Ann. of Nat. Hist.,' 2nd ser., vol. xi. p. 174.

with which we have a tolerable acquaintance:—and Thirdly, that certain *general principles* evolve themselves as results of these investigations, which are quite as applicable to every other department of Biological Science, as they are to the single case of the *Orbitolite.*

72. It has been shown that a very wide range of variation exists among *Orbitolites*, not merely as regards *external form*, but also as to *plan of development*; and not merely as to the shape and aspect of the *entire organism*, but also with respect to the size and configuration of its *component parts.* It would have been easy, by selecting only *the most divergent types*, from amongst the whole series of specimens which I have examined, to prefer an apparently substantial claim on behalf of these to be accounted as so many *distinct species*; and I could thus have easily created an almost indefinite number of such species. But after having classified the specimens which could be arranged around these types, a large proportion would yet have remained, either presenting characters *intermediate* between those of two or more of them, or actually *combining* those characters in different parts of their fabric; thus showing that no lines of demarcation can be drawn across any part of the series, that shall definitely separate it into any number of groups, each characterized by features entirely peculiar to itself. Thus, then, we see that the real relationship of the different types to each other, can only be determined by *the careful comparison of a very large number of individuals obtained from as many different sources as possible*;—a process which is too frequently neglected by Systematists, many of whom erect species, and even genera, without the least care to determine, by any such process, the real value of the distinctions by which they characterize them.

73. The right mode of proceeding in every other department of Natural History, must be that which has thus been proved to be the only reliable method in this; and I venture, therefore, to lay down the following general Canons, deduced from the results of the preceding investigation; which will, I think, be found accordant with the experience of all soundly-judging Naturalists, although they have not yet, so far as I am aware, received a formal expression.

74. To become fully acquainted with the Natural History of any Species, it is requisite;—(1) to study not only its external conformation, but also its *internal organization*; by which alone can the value of superficial resemblances or differences be duly estimated; (2) to trace out its entire *developmental history*, so that the true relationship of individuals in different stages of evolution may be appreciated; (3) to compare together a *large number of specimens* taken from any one locality, in order to ascertain what is the range of its variation under nearly identical conditions; (4) to search out its whole *Geographical distribution*, and to bring into mutual comparison large numbers of specimens from the remotest regions, as well as from all the intermediate areas over which it spreads, in order to determine the range of its variation under the most diverse conditions; and (5) to follow the same course of comparison throughout its *Geological distribution*, still relying only on the informa-

tion afforded by large numbers of specimens, collected (so far as may be possible) from different formations, and from different geographical areas. Until the whole of this process shall have been carefully and systematically gone through, no limitation of a species by a definition of any kind, can be regarded in any other light than as *a provisional means of marking-out the existence of a particular type of structure*, whose relationship to other types must be a matter of further investigation.

75. Let me subjoin such "pregnant instances," as shall prove the importance of each of the foregoing principles, from the result of the violation or neglect of it:—(1) so long as external conformation was alone regarded, and no account was taken of *internal organization*, the Nautiloid Foraminifera were placed among Cephalopods, and the Coralloid forms among Polypifera; to neither of which classes have they any kind of relationship; (2) so long as *developmental history* was unstudied, the Hydroid Zoophytes and the Medusoid Acalephæ were considered as entirely disconnected groups, belonging to two different Zoological classes, instead of (as in reality) different states of the very same organisms; (3) so long as reliance is placed on the comparison of a *few individual specimens* only, without any account being taken of the intermediate forms by which the more divergent types may be connected, so long are species multiplied to a most unwarrantable excess, as is found to be the case in almost every department of Zoology and Botany by those who devote themselves to a more extended comparison; thus, nineteen species have been made from the common *Potatoe*, and many more from the *Solanum nigrum*; so, multitudes of species have been instituted in various genera of Californian shells, by the late Mr. C. B. Adams, whose identity is established by a more extended comparison of individuals (as will be shown in a Report which is being prepared at the request of the British Association, by my brother, the Rev. P. P. Carpenter); in fact, wherever this test is conscientiously applied, its effect is to *reduce* the number of reputed species, sometimes in a most remarkable degree*. (4) In like manner it has been by comparing only a small number of specimens from remote geographical provinces, and by neglecting the intermediate varieties that present themselves even among sufficiently large collections from these, still more among specimens collected from intervening regions, that not only numerous errors of detail have been committed, but general doctrines have been propounded, which the advance of Science has proved to be utterly untenable. As an example of the former kind, may be cited the facts mentioned by Dr. J. D. Hooker (*op. cit.*), that of the New Zealand varieties of *Oxalis corniculata*, one of the most widely-diffused and most variable Flowering plants in the world, no less than seven or eight species have been made, neither of them supposed to be identical with any belonging to the European Flora; whilst *Pteris*

* I am most glad to find my views on this point in accordance with those of Dr. Joseph D. Hooker (see his 'Introductory Essay on the Flora of New Zealand,' § 2), who has been led to the conviction, that instead of affirming the existence of 100,000 species of known Plants, we ought not to reckon more than half that number.

aquilina has a different name in almost every country in the world. It has been through reliance on such ignorant determinations, most of them proceeding on the notion that "the plants (or animals) of newly-discovered, isolated, or little-visited localities must necessarily be new," that the doctrine of the universal distinctness of the species of the New World from those of the Old, and of those of the Southern from those of the Northern Hemisphere, has attained a very wide currency amongst Naturalists, and is still obstinately persisted-in by some, in defiance of ample evidence to the contrary*. (5) Lastly, not only has the limitation of the comparison among Fossil types, to a small number of individuals, led to the excessive multiplication of species in the forms that are furnished by the same strata; but the same habit of relying on minute differences, without attention to osculant characters, has given rise to that disposition to regard the species of successive formations as necessarily different, which is introducing the greatest confusion into geological and palæontological determinations of every kind. How an extended comparison of individual forms tends not only to reduce the number of reputed species, but to establish the continuity of the same specific types from one stratum to another, will be remarkably seen when the laborious researches of Dr. Wright of Cheltenham on the *Cidarites* of the Liassic and Oolitic formations shall have been made public.

76. Another general consideration of some interest, appears to me naturally to connect itself with the foregoing history,—namely, that the lower the general plan of organization of any being (that is, the greater the prevalence of 'vegetative' or 'irrelative' repetition in its different parts), the more is that plan liable to be modified by slight differences in external conditions, and the wider, therefore, may we expect its range of variation to be, if it be disposed to vary at all. In some instances, it is true, there appears (as in many higher forms of organization) to be an absolute incapacity for any such variation; and a limitation of the geographical and geological distribution of the species results from its want of power to exist under any great diversity of external conditions. But when the same general type of organization is found to prevail extensively both in space and in time, it may, I think, be safely regarded as probable, that that type has within itself the power of accommodation to a considerable diversity of external conditions; and hence that in the comparison of individuals, differences of conformation should be considered as of less account towards the establishment of specific distinctions, than they are when there is an obvious restriction of the type to a limited Geographical area or a particular Geological epoch.

77. In the foregoing communication, I have thought it right not only to make known the *results* of my researches, but so to develope my *plan of investigation*, that the value of those results may be duly estimated. In the memoirs which I trust to be

* "Thus as long ago as 1814, Mr. Robert Brown gave a list of 150 European plants common to Australia and Europe. The identity of many of these has repeatedly been called in question, but almost invariably erroneously; added to which, more modern collectors have greatly increased the list."—Hooker, *op. cit.* p. 18.

enabled to forward from time to time, regarding those other typical forms of Foraminifera of which I have made a special study, it is not my intention to do more than state the *results*; hoping that they may be understood to have been attained by a method of inquiry as closely resembling that which I have here followed through its details, as the circumstances of each case may have admitted. I would have it borne in mind throughout, that, as has been admirably remarked by one of the most accomplished Botanists of our time, "the Naturalist who has the true interest of science at heart, not only feels that the thrusting of an uncalled-for synonym into the nomenclature of science is an exposure of his own ignorance, and deserves censure, but that a wider range of knowledge and a greater depth of study are required, to prove those dissimilar forms to be identical, which any superficial observer can separate by words and a name" (Dr. J. D. Hooker, *op. cit.* p. 14, note).

EXPLANATION OF THE PLATES.

PLATE IV.

Structure of the Animal *of Orbitolite.*

Fig. 1. Entire Animal, from a small and simple disk, the shell having been removed by maceration in acid; in the peripheral portion the segments of sarcode are wanting, and the structureless residuum of the shell is alone seen:—magnified 40 diameters.

Fig. 2. Appearance of a portion of Sarcode, highly magnified:—180 diam.

Fig. 3. Portion of the body of one of the more complex forms (resembling fig. 4), in which the sarcode has broken up into little spheres (gemmules?);—*a, a,* superficial segments; *b, b,* annular band:—180 diam.

Fig. 4. Portion of the body of one of the more complex forms, as seen in *vertical* section;—*aa, a'a',* upper and lower rows of superficial cells, each cell connected, at its two extremities, with the annular bands *bb* and *b'b'* of *two* zones; from these annular bands spring the columnar segments *cc, c'c',* those of the same zone occasionally passing into each other, and communicating with those of the next zone by oblique peduncles alternately passing towards one side and the other:—150 diam. (N.B. This figure is somewhat *ideal,* being made-up from several preparations; but for every point which it represents, these preparations give warranty.)

Fig. 5. Nucleus and first two annular zones, exhibiting the typical conformation;—*a,* the central segment; *bb,* the circumambient segment, from the entire margin of which are given off peduncles of sarcode, which give origin to the first annular zone:—84 diam.

Fig. 6. Nucleus and first two annular zones of another disk, showing a deficiency in the connexions of the first annular zone with the circumambient segment *bb*, for about a third of the circumference of the latter, between the points *cc*:—84 diam.

Fig. 7. Portion of one of the *surfaces* of an animal of complex type (as in fig. 4):—*aa, aa,* rows of superficial cells, connected at their two extremities with the annular bands *bb, bb*:—150 diam.

Fig. 8. Portion of fig. 1, enlarged, to show the ordinary mode in which the segments of each zone are connected by peduncles with the *annular band* of the preceding zone, so as to alternate with its segments; showing also the occasional interpolation of additional segments, *a, a,* whose peduncles come off from the *segments* of the preceding zone:—90 diam.

Fig. 9. Portion of a section of the shelly disk enlarged, to show the corresponding appearances it presents; each cell being ordinarily connected by a radial passage with the *annular canal* of the preceding zone, and thus with the two cells alternating with itself; but cells *a, a,* being sometimes interpolated, which open directly into the *cells* of the preceding zone:—90 diam.

Fig. 10. Central and circumambient segments (*a* and *bb*) of a large disk, showing the origin of the segments of the first annular zone, *c, c,* from less than half the circumference of the nucleus:—84 diam.

Fig. 11. Peculiar bodies (ova?) found in the substance of the sarcode in different parts, showing successive stages, *a, b, c, d, e, f,* of binary subdivision; *g,* other bodies of somewhat larger size, found in one of the superficial cells of a vertical section:—130 diam.

Fig. 12. Central portion of fig. 1, enlarged to the same scale as figs. 5, 6, 10; showing the central segment *a*, the circumambient segment *bb*, and the origin of the first annular zone in *three* peduncles proceeding from the end of the latter:—84 diam.

Fig. 13. Central portion of another disk, showing the origin of the first annular zone by *eight* peduncles from the circumambient cell:—84 diam.

PLATE V.

Structure of the Calcareous Disks *of Orbitolite.*

Fig. 1. Ideal Representation of a Disk of the Simple Type, the details of the different parts made-up from actual specimens; showing the natural surface, with the markings of the cells; the natural margin, with the single row of pores between the protuberances of the cells;—a portion of the interior, as displayed by a *horizontal* section, showing the central cell *a*, the circumambient cell *b, b,* the concentric zones of cells *c, c,* with the annular passages which connect together the cells of the same zone, and the radiating passages

which extend from the annular passages of each zone to the cells of the next, and, in the outermost zone, to the pores *d, d*;—another portion as displayed by a *vertical* section *e, e*, in a *radial* direction, which lays open the columnar cells, but passes through the intercellular partitions, in alternate zones;—and another portion *ff*, as displayed by a fracture in the course of one of the zones, laying open the entrances to the cells from its inner or central side.

Figs. 2, 3. Two large recent disks from the Feejee islands, plicated towards the margin, but one much more so than the other, and with a projection of the upper and lower edges, so as to leave a deep marginal furrow:—enlarged 2 diam.

Figs. 4, 5. Vertical sections of two disks, drawn under the same magnifying power, showing the marked difference in the size and proportions of their parts. In each disk we see the central cell, with the circumambient cell laid open on either side of it; and the cells of successive zones, with their communications:—30 diam.

Fig. 6. Ideal Representation of a Disk of the Complex Type; the details of the different parts made-up from actual specimens:—*a*, central cell; *b*, circumambient cell; *c, c*, concentric zones of oblong superficial cells, some of them laid open; *d, d*, marginal pores, forming several rows; d'', d''', corresponding pores of inner zones, once marginal, but now connecting them with surrounding zones; *e, e*, vertical section in a radial direction, showing the zones nearest the centre to be made up of simple columnar cells, but those of the remainder of the disk to be composed of two superficial layers and of an intermediate stratum; *f, f*, floors of the superficial cells, with an aperture at each end of every one; *g, g*, annular canals, running beneath these floors, with the large apertures leading to the columnar cells of the intermediate stratum; g', the same canals near the other surface of the disk; g'', the same canals laid open through the plane at which they give off the two passages into the superficial cells; g''', the same canals, as cut transversely by a vertical section; *h*, passage of the horizontal section through the intermediate stratum, showing the summits of its columnar cells about to enter the annular canals; *i, i, i*, and *k, k, k*, passage of the horizontal section through two different planes of the intermediate stratum, showing the connexion between the columnar cells of successive zones, by oblique passages running in different directions; *l*, portion immediately surrounding the nucleus, formed upon the simple type, as in fig. 1.

Fig. 7. Vertical section, taken in a radial direction, of a recent disk incompletely developed on the complex type; showing at *a*, a single chamber of the cavity of the nucleus, the section having traversed the circumambient cell; from *a* to *b*, including twenty-three zones, the disk developed upon the simple

type; from *b* to *c* the annular canal double, and an irregular intermediate stratum interposed, from which, however, the superficial cells are not completely differentiated; and from *c* to *d* the imperfect separation of the superficial cells from the intermediate layer, and the extreme irregularity of the latter:—50 diam.

Fig. 8. Tangential section, near the margin of the same disk, showing the same peculiarities:—50 diam.

Fig. 9. Central portion of a disk, showing the nuclear cavity divided into two (the section having traversed the central cell and one side of the circumambient); the formation of the first three zones (*a*—*b*) on the simple type; the imperfect separation of the superficial cells from the intermediate stratum in the next two zones (*b*—*c*); and the regular development of the remainder (*c*—*d*) on the complex type:—50 diam.

Fig. 10. Vertical section of the central portion of a disk of complex type; showing *four* cavities in the nucleus; the first five zones (*a*—*b*) constructed upon the simple type, with a single annular canal, but an incipient separation manifesting itself between the superficial cells and the intermediate stratum; in the next three zones (*b*—*c*) the annular canal double, but the superficial cells still partly continuous with the columnar; the outer part (*c*—*d*) framed according to the regular complex type:—48 diam.

Fig. 11. Vertical section of a disk of complex type, showing an unusual development of vertically superposed cells immediately around, and even partly covering, the nucleus, from which they arise by four layers of passages; a progressive diminution in the thickness of the disk, as far as the fifth zone (*b*), with a gradual approximation towards the regular type, on which the remainder (*b*—*c*) is developed:—48 diam.

Fig. 12. Vertical section of a disk of complex type, showing commencement of its first zone by a single layer of passages (*a*) from the nucleus; the presence of two annular canals, with the absence of separation of the superficial cells, in the first zone (*b*); the incomplete separation of the superficial cells from the intermediate columnar portion in the second zone (*c*); and the normal conformation of the remainder (*c*—*d*):—48 diam.

PLATE VI.

Fig. 1. Portion of a disk of simple type, from the immediate neighbourhood of the nucleus, showing the beak-like projections at the sides of the passages very remarkably developed:—100 diam.

Fig. 2. Horizontal section of the intermediate layer, passing (in consequence of the flexure of the disk) through two different planes, and thus showing the two different directions of the oblique passages which connect the colum-

nar cells of different zones; also showing a marked difference in the size of adjacent cells:—100 diam.

Fig. 3. Horizontal section through one of the superficial layers, showing the elongated form of its cells, and the aperture at each end of their floor:—100 diam.

Fig. 4. Nucleus and surrounding zones of the excentrically-developed disk shown in Plate IX. fig. 3; the beak-like projections at each side of the pores opening into the new zones (shown in fig. 1) are here generally deficient:—100 diam.

Fig. 5. Appearance of the thin wall covering-in the central cell of a large nucleus, as seen under a high magnifying power, showing the quasi-cellular markings:—100 diam.

Fig. 6. Horizontal section through the intermediate layer of a disk of complex type, showing an unusual irregularity in the communications of the cells:—100 diam.

Fig. 7. Radial section of a recent disk, showing the complex development on the normal type; *aa, bb*, upper and lower superficial layers; *c, c, c, c*, intermediate stratum; dd, $d'd'$, $d''d''$, summits of partitions between successive zones, forming the floors of the superficial cells; e, e', e'', oblique passages through the floors of the cells of the superficial layer, leading towards the annular canals; f, f', f'', f''', annular canals of four zones, near the lower surface of the disk; *gg*, partitions between the adjacent cells of the same zones; *hh*, perforations in these, through which the columnar cells inosculate with each other:—100 diam.

Fig. 8. Tangential section of a fossil disk of complex type, showing four columnar cells, aa', bb', cc', dd', of the same zone, divided by sinuous partitions, with the orifices leading into the columnar cells of the next interior zone:—100 diam.

Fig. 9. Similar tangential section, showing four cells of the next interior zone, aa', bb', cc', dd', alternating with the preceding, and the entrance of the passages of the same vertical row, alternately into one and the other of the cells on the two sides of each of the sinuous vertical partitions:—100 diam.

Fig. 10. Radial section of a fossil disk, showing the incompleteness of the separation of the superficial cells from the intermediate layer, and the irregularity in the arrangement of its cells, with their numerous lateral inosculations (compare Plate V. fig. 7, *b—d*):—48 diam.

Fig. 11. Radial section of a thicker fossil disk, showing a more regular arrangement of the columnar cells of the intermediate layer (still, however, with numerous passages for lateral inosculation), and the complete continuity of the superficial cells with these:—48 diam.

PLATE VII.

Figs. 1—4. A series of specimens, drawn under the same magnifying power (35 diam.), illustrating the variations which present themselves in regard to the *Size* of the nucleus.

The remaining figures represent various appearances exhibited by the *Surfaces* of Disks, simple and complex:—all magnified 35 diam., except fig. 6, which is magnified 70 diam.

Figs. 5—7. Portions of surfaces of simple disks, in which the concentric circles are strongly marked, and the transverse divisions of the cells are comparatively obscure.

Fig. 8. Simple disk, slightly concave, the marginal cells laid open by abrasion, the surface marked rather by 'engine-turned' or excentric, than by concentric circles.

Fig. 9. Portion of the surface of a complex disk, having small, round, and flattened superficial cells.

Fig. 10. Simple disk (from Australia), slightly concave, the marginal cells laid open by abrasion, the surface irregularly thickened by calcareous deposits.

Fig. 11. Flattened simple disk (from the Philippines), with abundant superficial deposits, arranged with considerable regularity in a radiating direction.

Fig. 12. Portion of the surface of a large complex disk, with very narrow oblong superficial cells.

Fig. 13. Portion of the surface of a complex disk, showing a marked difference in the proportions of the straight-sided cells, even in adjacent zones.

Fig. 14. Surface of simple disk (*Cyclolina*? of D'Orbigny), with an excentric nucleus, surrounded by strongly-marked concentric circles.

Fig. 15. Portion of the surface of a simple disk, showing unusually large and protuberant ovoidal cells.

Fig. 16. Portion of the surface of a large fossil disk of complex type, showing varieties in the size and form of the superficial cells.

PLATE VIII.

Fig. 1. Inner surface of a zone of a thick fossil disk, showing a tolerably regular arrangement of the columnar cells, the segmental constrictions of these, and the fissures leading into those of the next row:—35 diam.

Fig. 2. Outer surface of a similar zone, showing the continuity of the cells of the superficial layer with the vertical columns of the intermediate (the latter not unfrequently dividing, however, at their extremities, so as to form two cells at the end of each column), and the pores leading to the oblique

passages, directed alternately to one side and to the other, which lead to the cavities of the columnar cells:—35 diam.

Fig. 3. Horizontal section of the intermediate layer, immediately beneath the floors of the superficial cells, laying open the annular canals, with the summits of the columnar cells:—100 diam.

Figs. 4—9. Various examples of the *Reparation* of disks after fracture, and of the growth of new disks from detached fragments. For description, see ¶ 37—40 of Memoir. Fig. 6 is magnified 6 diam.; the rest 35 diam.

Fig. 10. Monstrosity formed by the inclusion of a young disk within the outer zones of an older one, that seems to have been brought into contact with it by the progressive increase of its own diameter:—25 diam.

PLATE IX.

Figs. 1—4. Various departures from the typical mode of concentric development, presented in their early state, both by simple and complex disks; some of them even passing towards a spiral mode of evolution. Figs. 1 and 3 are magnified 35 diam.; Figs. 2 and 4 are enlarged 90 diam.

The remaining figures show various forms of *Monstrosity*, produced by excess of growth from the nucleus.

Fig. 5, 6. Two views of a disk from the Philippine shores, having a single plane on one side, and two planes, meeting at an acute angle, on the other:—6 diam.

Figs. 7, 8, 9. Small Australian disks, with vertical crests:—35 diam.

Fig. 10. Disk from the Ægean Sea, with a tri-radiate crest:—35 diam.

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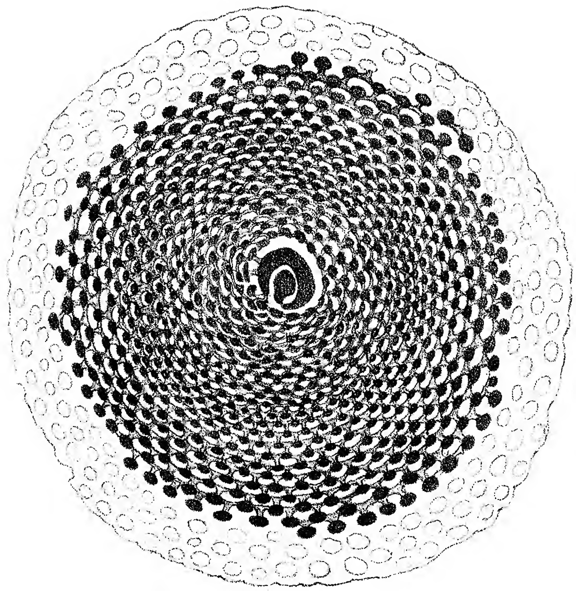

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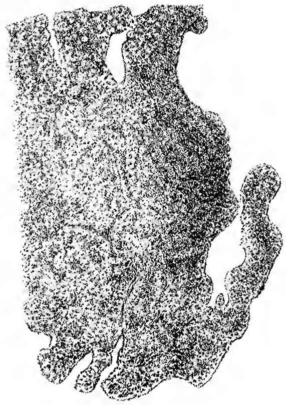

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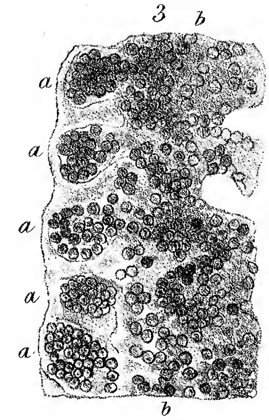

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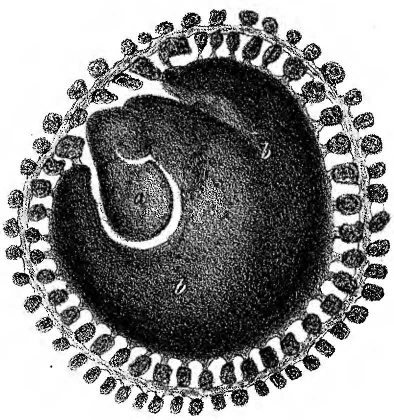

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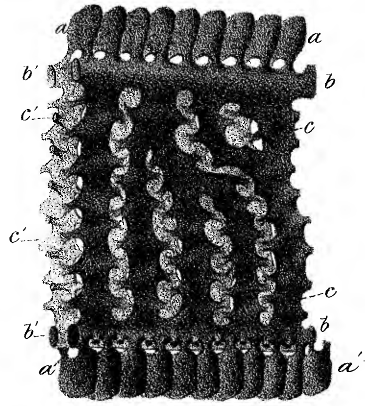

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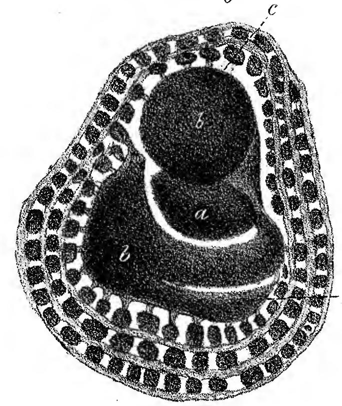

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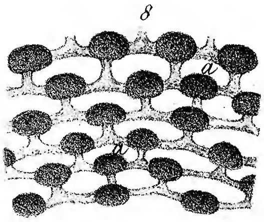

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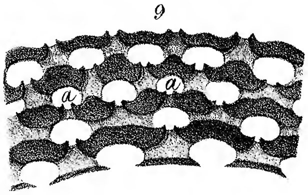

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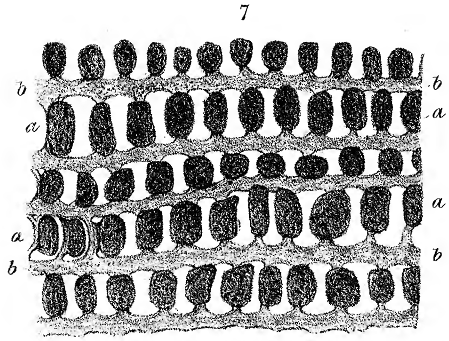

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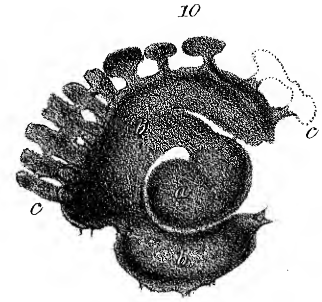

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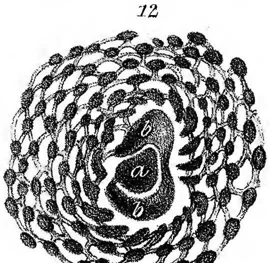

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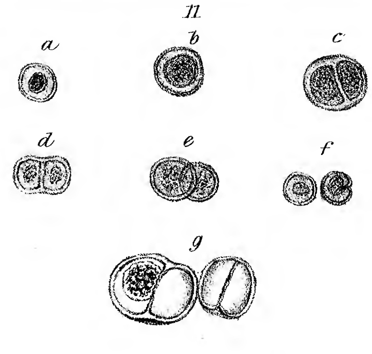

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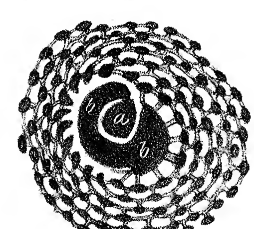

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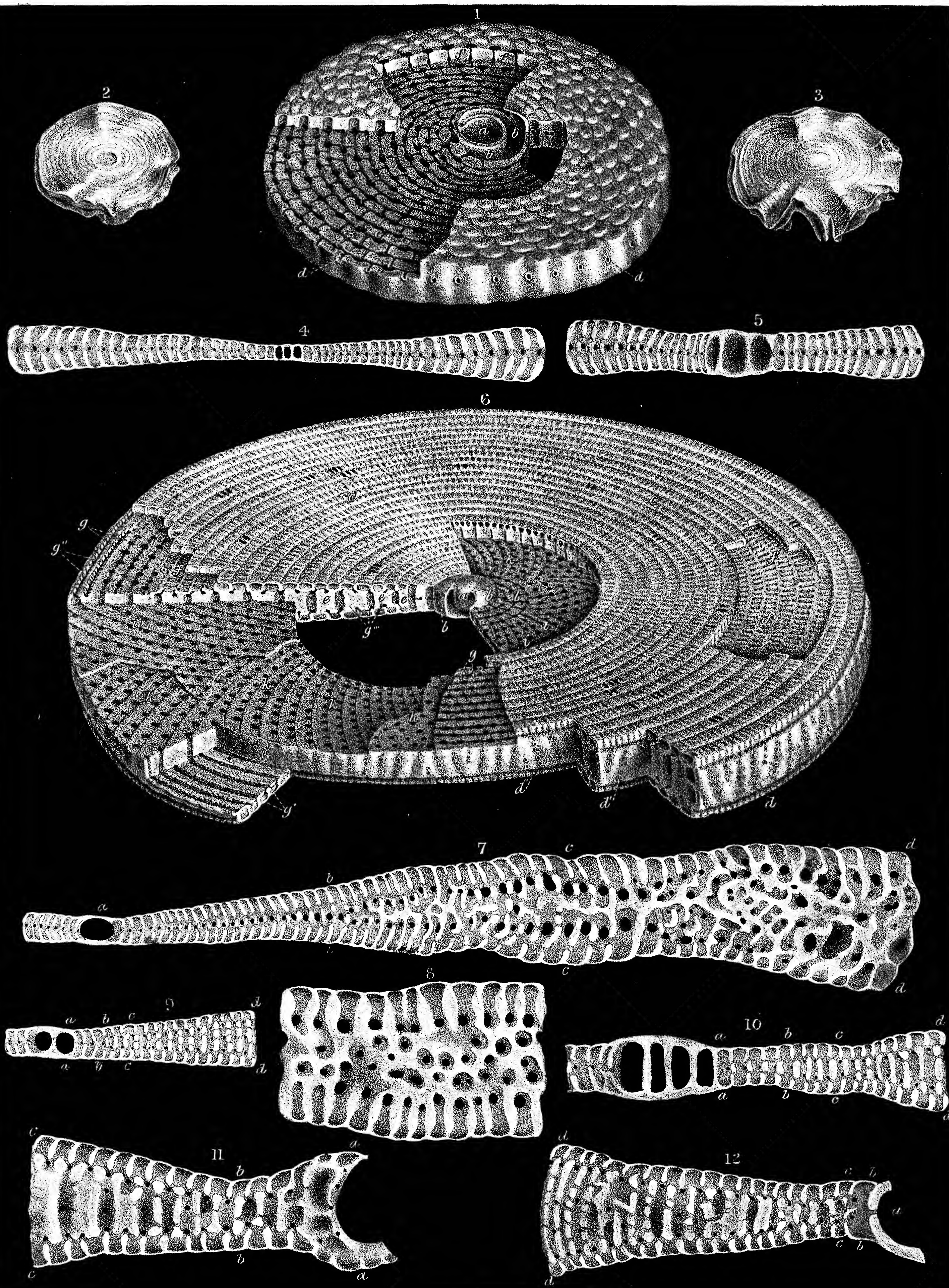

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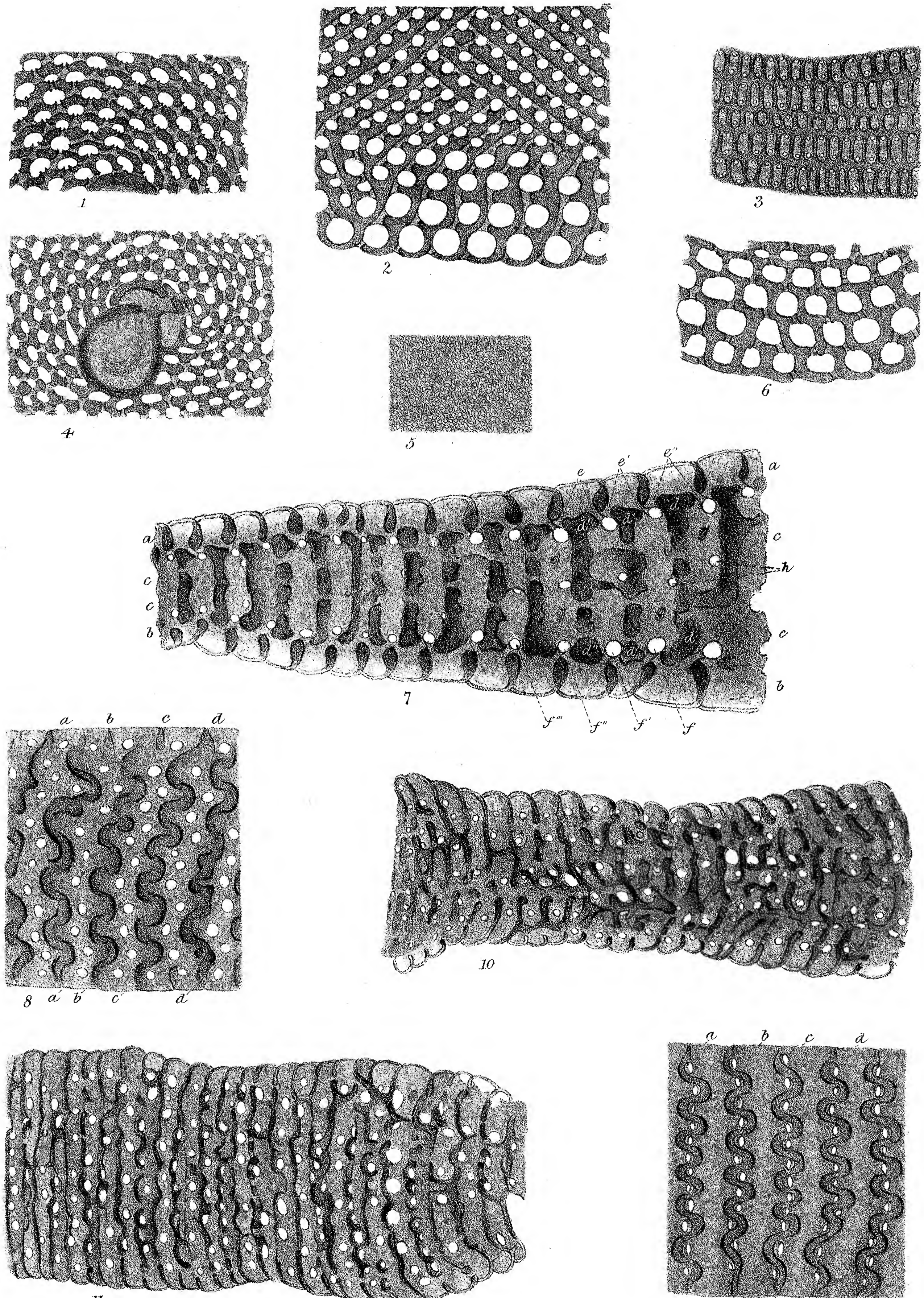

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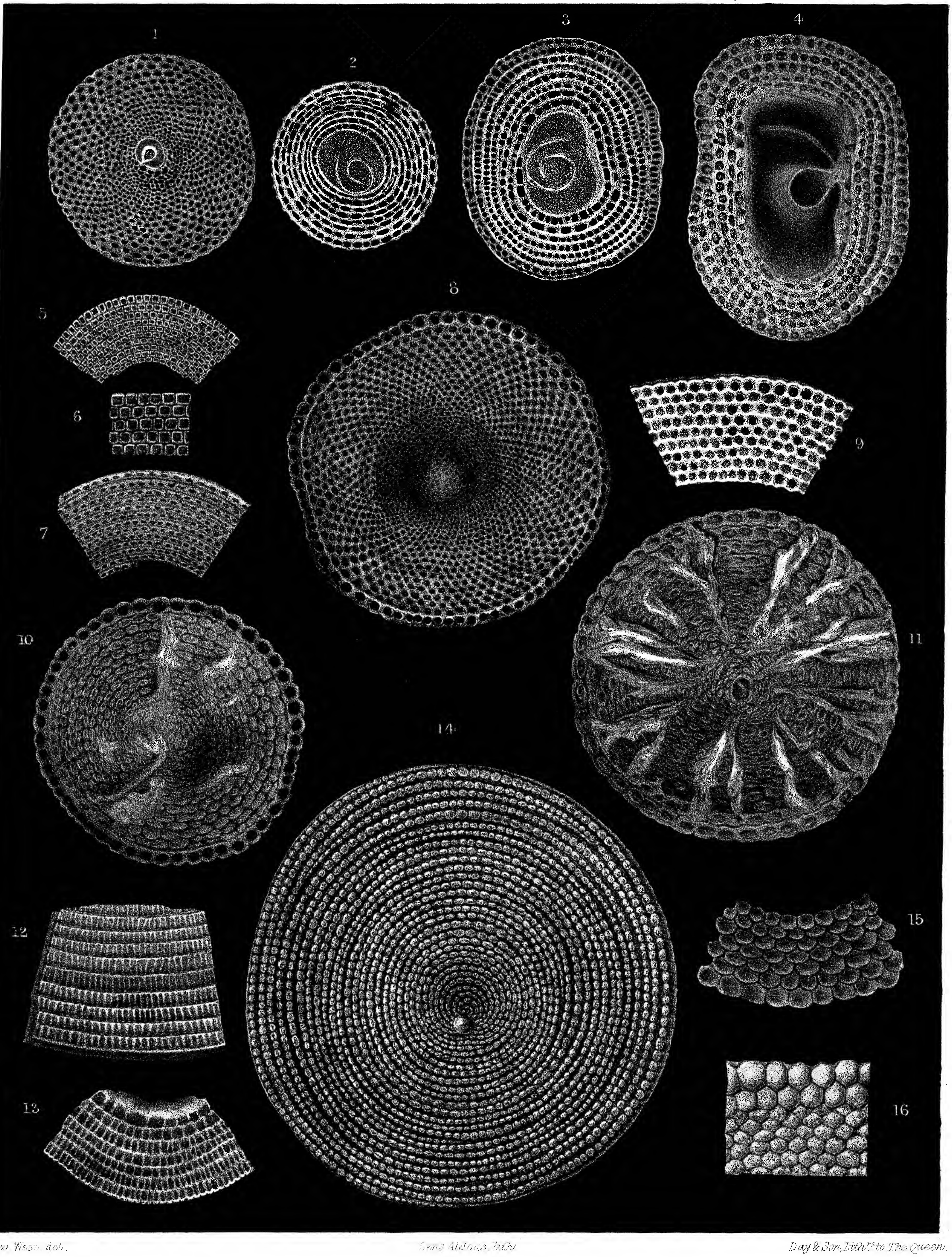

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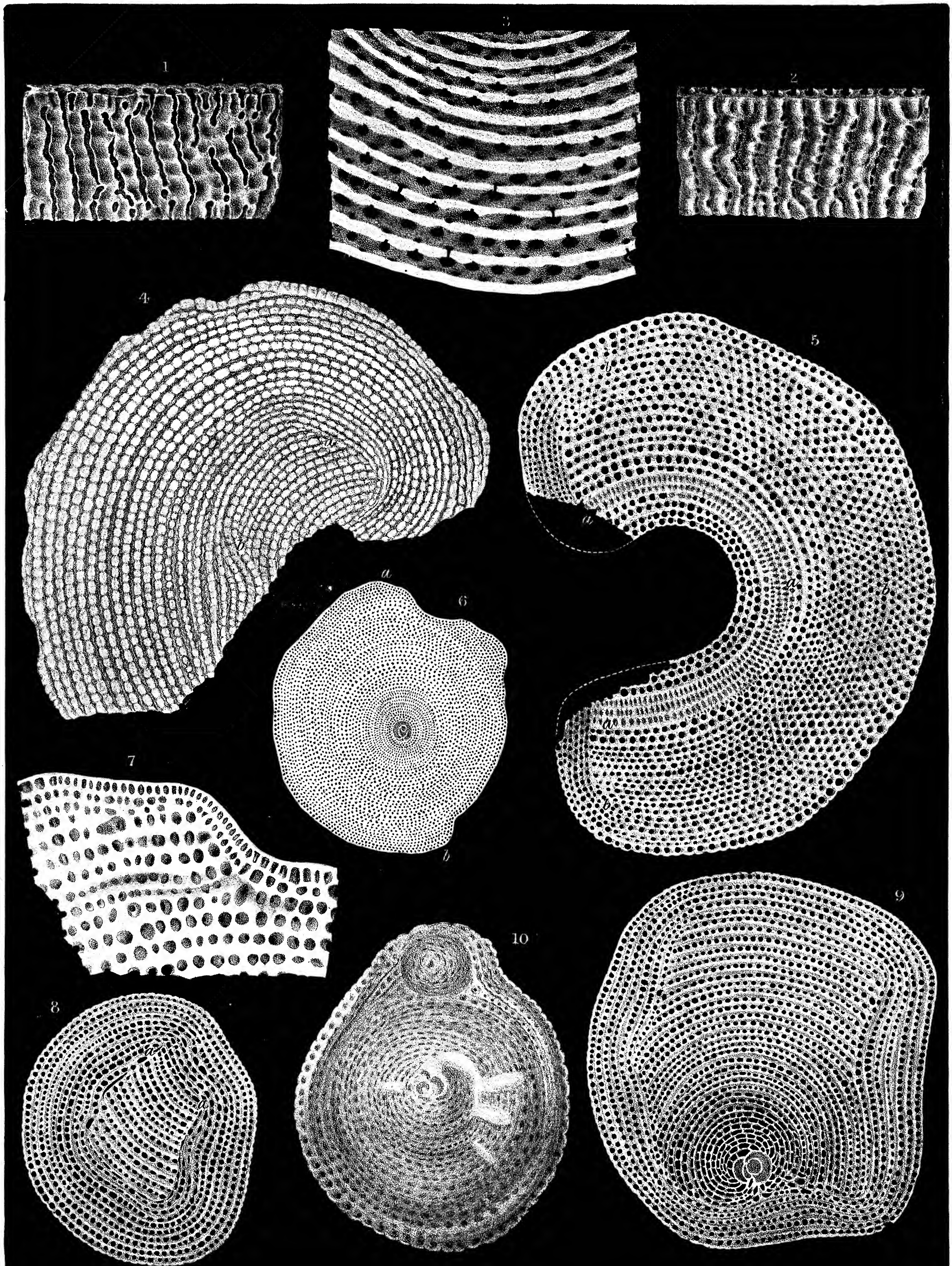

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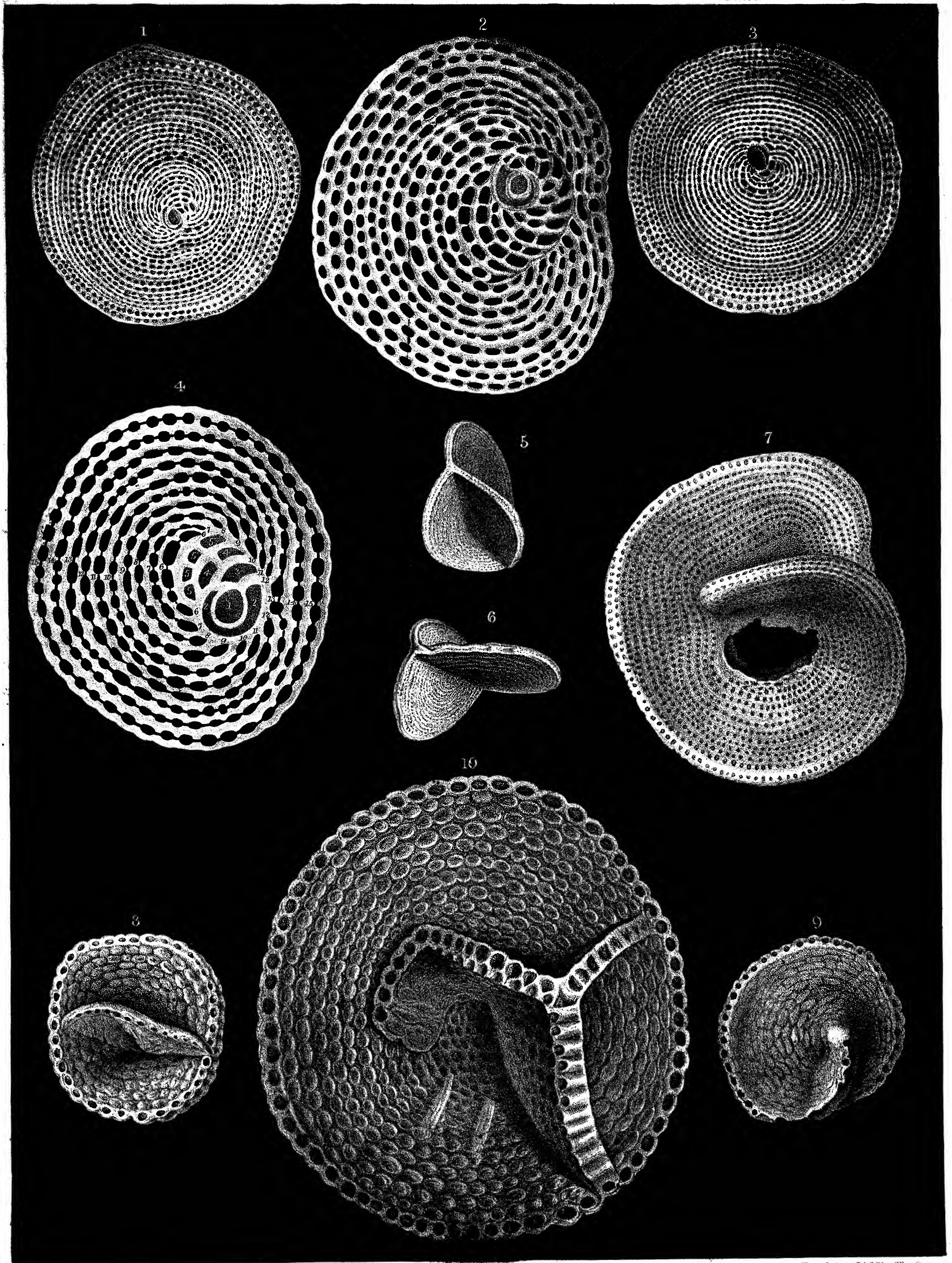

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